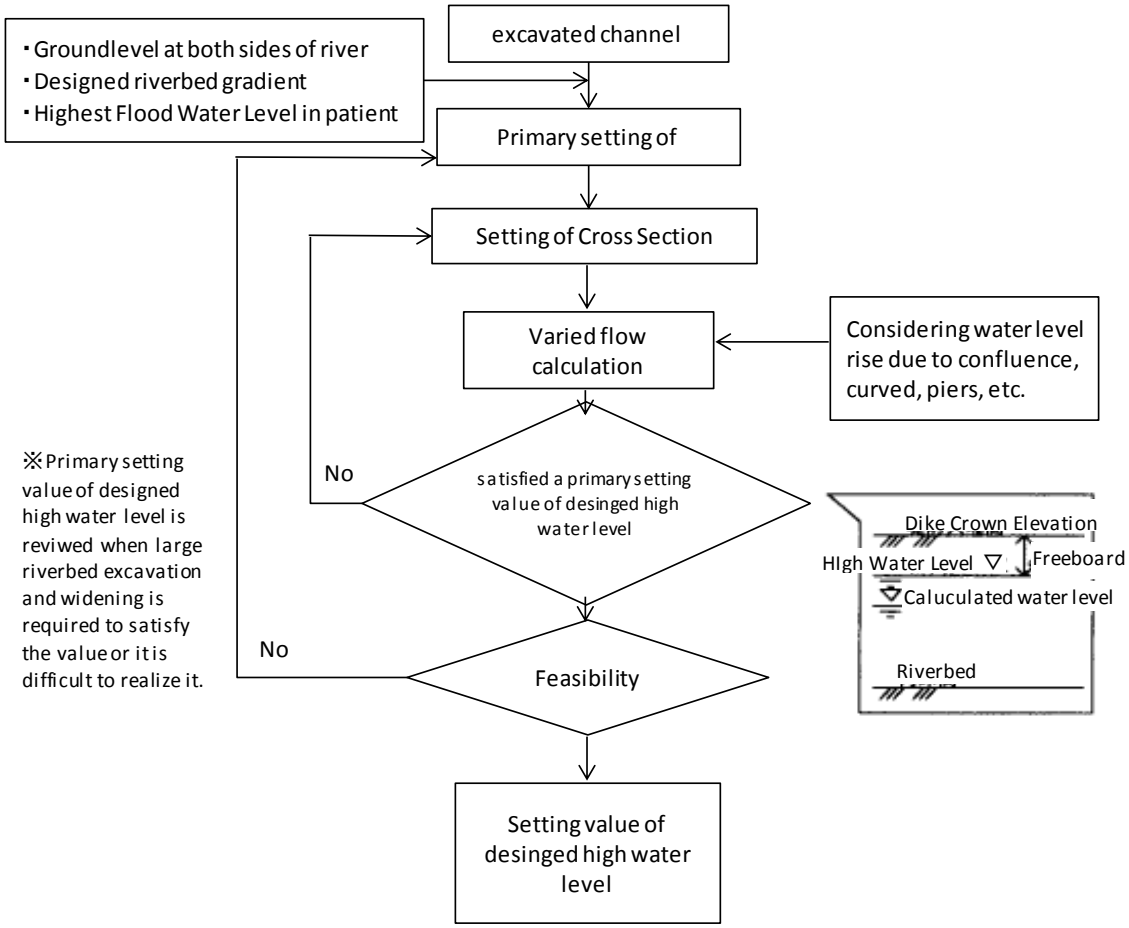
7.3 Consideration of Channel Improvement Plan as an alternative flood control measure

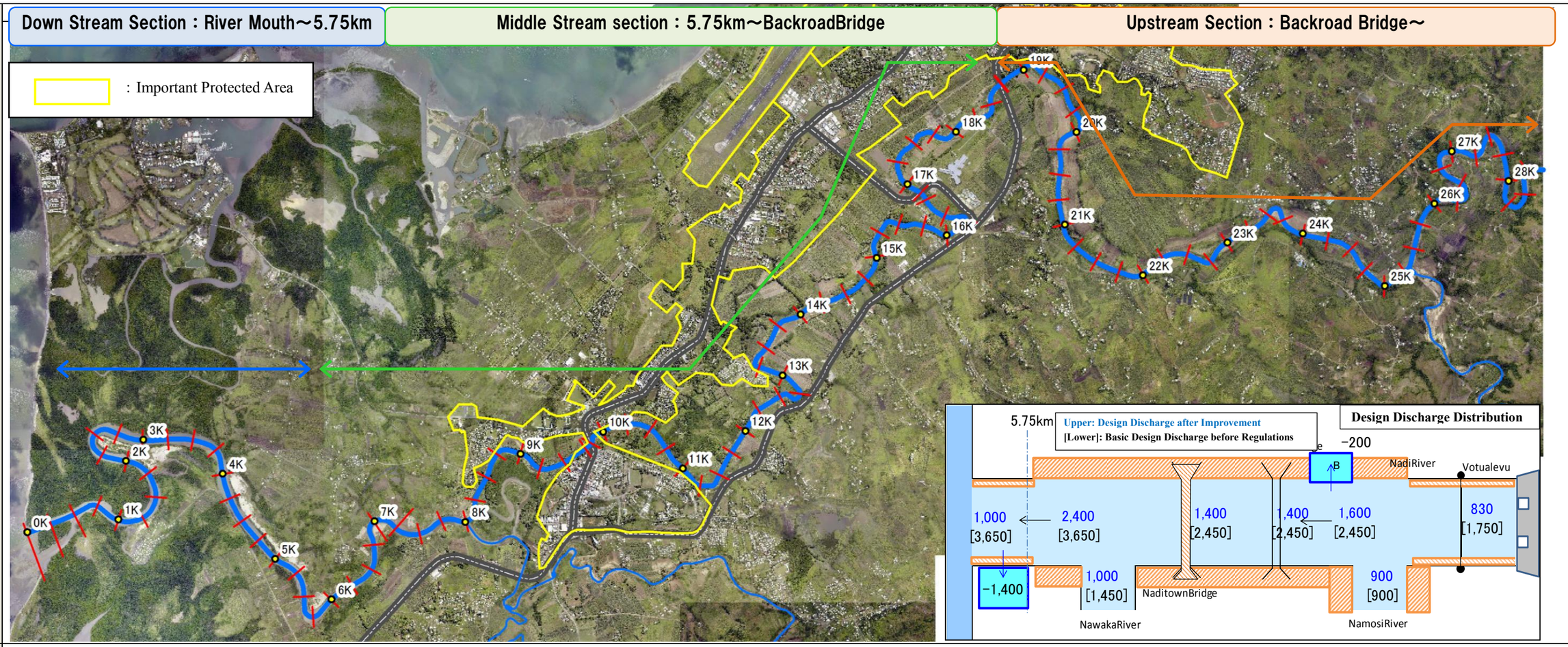
The flow capacity of the Nadi main stream is shown in the Figure 7-5. Compared with the design flood discharge, the flow capacity is insufficient so that the suitable river channel improvement is required. In river improvement plan, the improved channel section is established by following study flow considering design flood discharge shown in Figure 7-2.



Source: Guidline of middle and small sized rivers planning (draft) in Japan September 1999

Figure 7-4 Standard Flow of River Improvement Plan

Plan



Flow Capacity

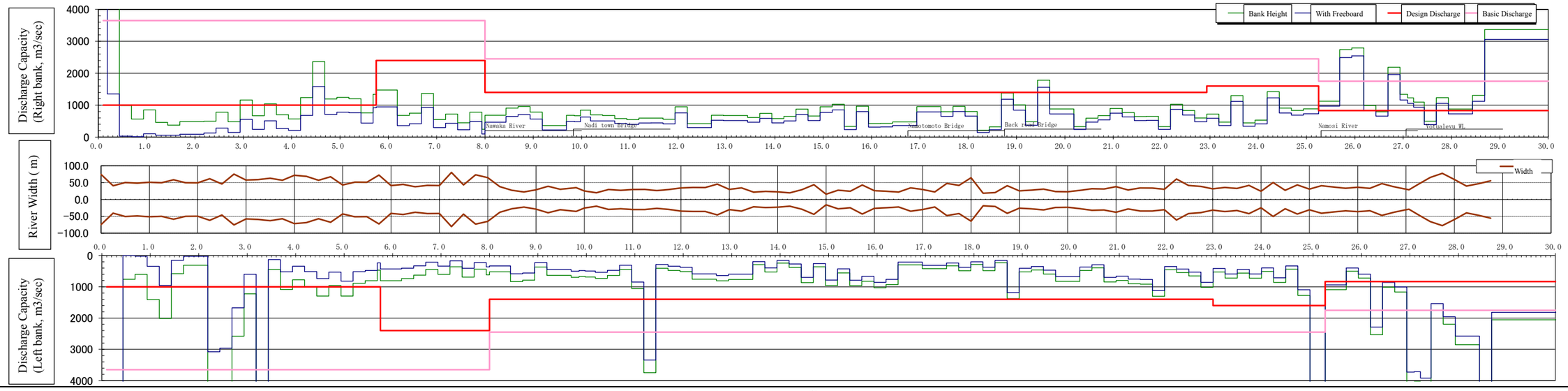


Figure 7-5 Present Flow Capacity

7.3.1 Planning of Alignment of River Improvement

It is necessary to decide channel alignment considering hydrological characteristics and land use along river comprehensively. Standard policy for alignment plan in Nadi River is shown in following.

- The Nadi river is natural river although the places where housing gathers densely are observed occasionally, Channel alignment is to be followed basically to the present situation, however in the places of sever bending (around 13.00km and 16.00km) it is revised with smooth curve (as to the rising of water level in such bending places, the alignment will be confirmed on the final solution in 8.2.2).
- From view point of equality to the residents along river, expanding the both side of bank is basic policy, however one side of expanding will be carried out depending on distribution of housing to avoid relocation as much as possible and topographic condition of landside of bank.

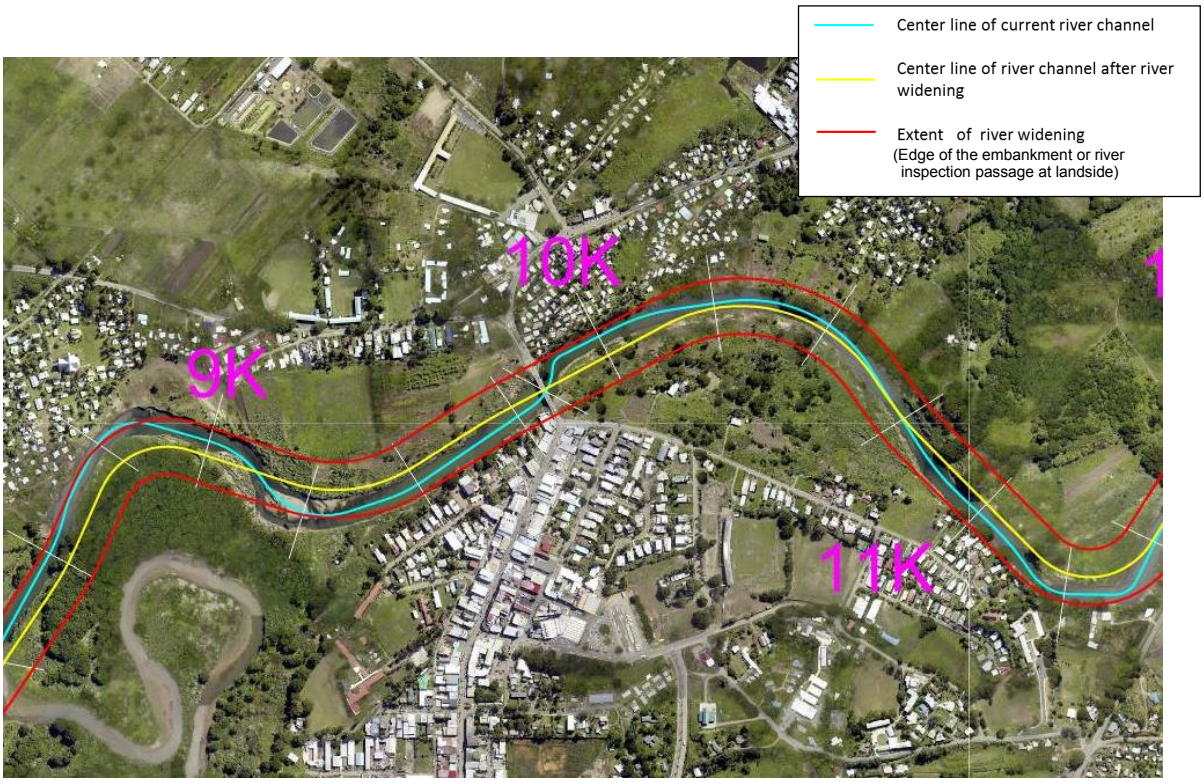


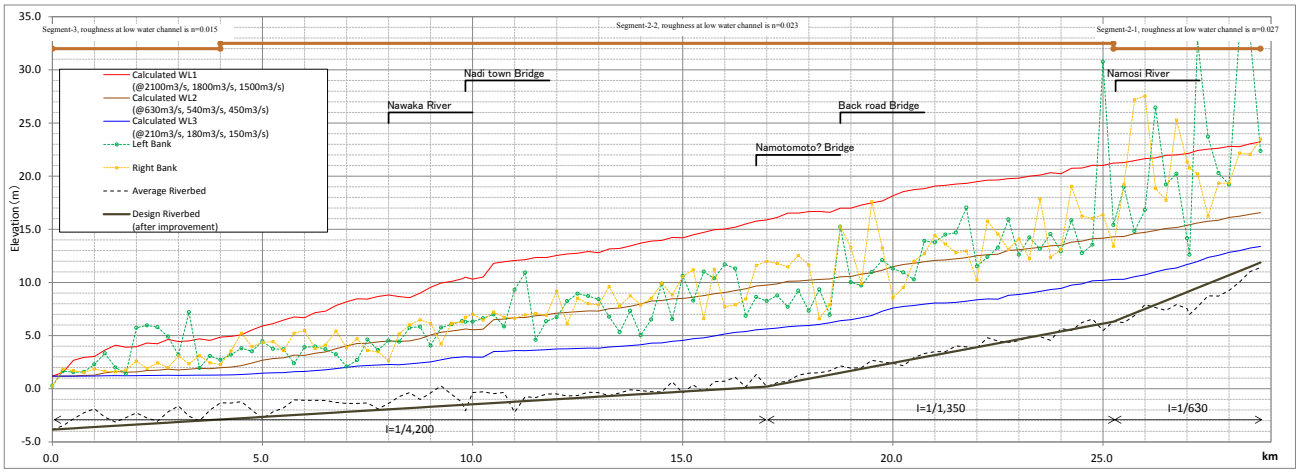
Figure 7-6 Preliminary Plan of Alignment

7.3.2 Planning of Profile of River Improvement

In the plan of profile of river, it is preferable that the high water level is to be less than the ground level outside of river channel so that the high water level and the profile of riverbed is planned following the basic policies shown below.

- Design high water level is established less than the ground level outside the river channel as much as possible.
- Design riverbed height is basically same as the present riverbed.
- Design riverbed slope is basically same as present slope considering to secure river bed safety

The design profile is as shown in Figure 7-7 which is planed preliminary and will be revised in the finally selected river improvement plan. The final plan is shown in 8.2.3



※ The calculated water level is the result of preliminary trial calculation.

Figure 7-7 Preliminary Plan of Profile

7.3.3 Planning of Cross Section of River Improvement

In the cross section plan it is required that to secure sufficient cross section area to discharge the design discharge under the design high water level as well as to consider land use and natural environment along the river. The basic policy of cross section planning is as shown below.

- The slope of river side is to be basically 1:2.0 considering that the present slope is approximately 1:2.0 and to void relocation and land acquisition as much as possible and the land side slope is to be basically 1:3.0 considering the safety against seepage. The stability analysis for slope sliding and seepage will be carried out in the Feasibility Study. (In addition, this longitudinal draft plan was carried out at the initial examination and the finally selected cross-sectional plan with the optimal combination plans is carried out in 8.2.4.)
- Against the riverbank erosion, the bank protection is installed at water colliding front such as outside of bend..
- In some section gathering many houses, river side embankment is constructed to avoid relocation of housing.

The examples of planned cross section are as shown in Figure 7-8.

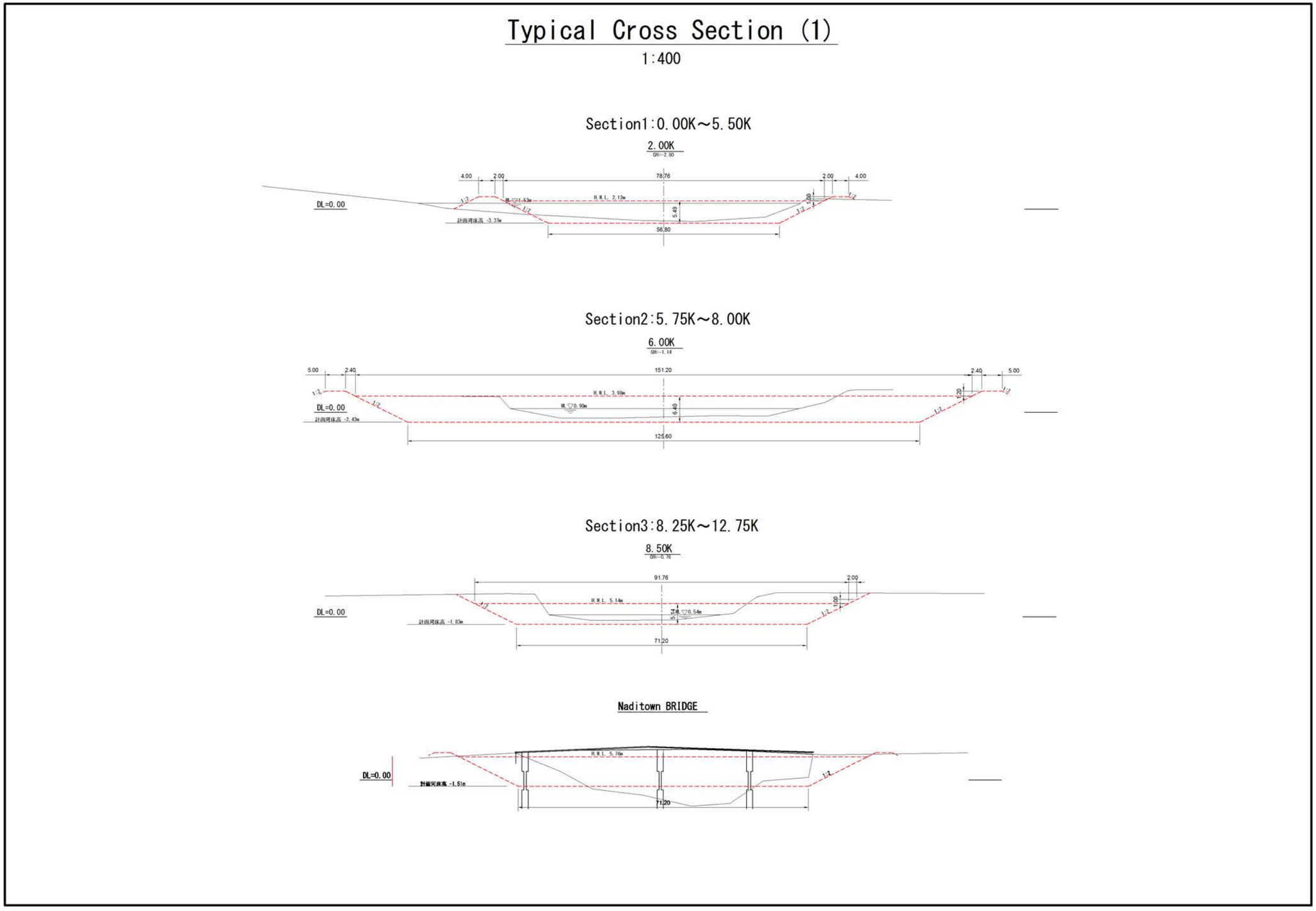


Figure 7-8 Examples of Present Cross Section (solid line) and Design Cross Section (broken line)

7.4 Consideration of Retarding Basin as an alternative flood control measure

The preliminary consideration of retarding basin is described in 6.3.2 and the required retarding basin (or group of basin) in the downstream section, middle stream section and upstream section are selected and examined in 7.7 in which the optimal combination of the flood control structures is studied.

7.5 Consideration of Diversion Channel as an alternative flood control measure

7.5.1 Alignment of Diversion Channel

Policy of planning of alignment of diversion channel is as described below.

- Diversion channel is to be diverted at the straightway of the Nadi river.
- The alignment is set avoiding impact on land use and houses as much as possible. Especially, it is kept away from planned expansion area for runway of Nadi airport.

Figure 7-9 Planned Alignment of Diversion Channel

7.5.2 Planning of Profile of Diversion Channel

Design high water level and design riverbed height are established based on the following standard policy.

- Design high water level is set based on result of varied flow calculation in case of 700m^3/s flowing down and the design high water level at diverting point in the main stream.
- Design bed height is set securing enough water depth for 700m^3/s flowing down, and it will be examined in Stage-2 of the Study considering influence by saline water running up.
- Design riverbed slope is set considering influence by saline water and diverted discharge from the main stream.

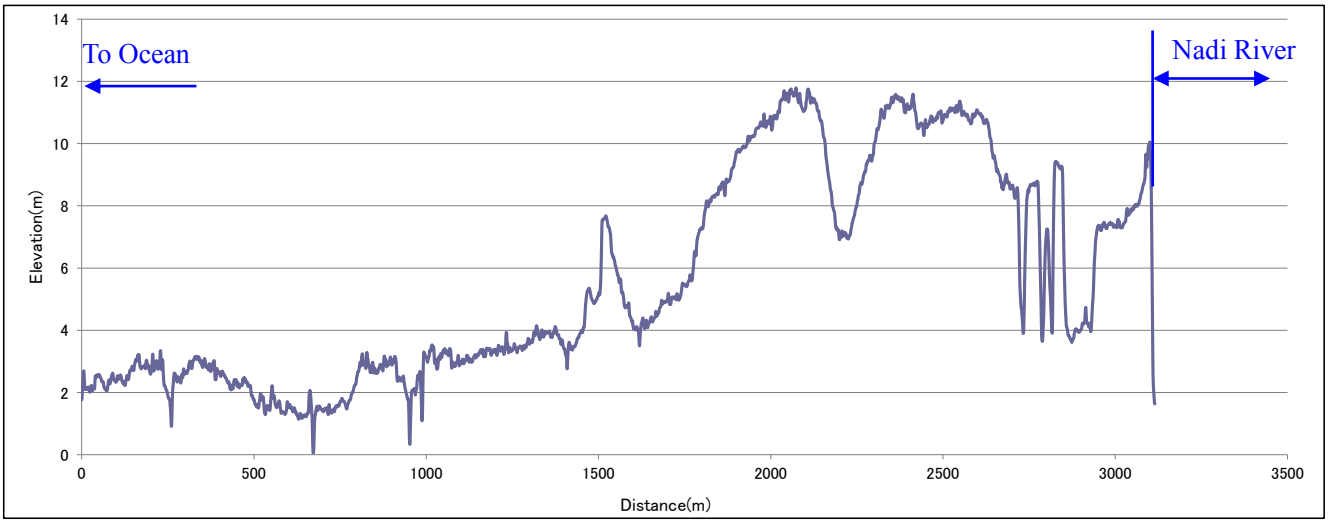


Figure 7-10 Ground Level along Diversion Channel

7.5.3 Planning of Cross Section of Diversion Channel

In the cross section plan it is required that to secure sufficient cross section area to discharge the design discharge under the design high water level as well as to adjust the cross section of diversion channel with that of main stream so that the diverted discharge will be equal to the planned discharge
The basic policy of cross section planning is as shown below.

- Design cross section is set to adjust the cross section of diversion channel so that the diverted discharge is equal to the planned diverted discharge considering shape of cross section and water surface slope of channels.
- The slope of river side is to be basically 1:2.0 and against the riverbank erosion, the bank protection is installed at water colliding front.

7.6 Consideration of Flood Control Facilities in Tributaries as an alternative flood control measure

7.6.1 Layout of Flood Control Facilities

The design flood discharge in the tributaries of Nawaka and Malakua Rivers is determined considering the flooding conditions in the flood March 2012 as well as that of Nadi River main stream, which is designed as 1,000m^3/sec at the confluence of Nadi main stream.
On the other hand the both tributaries flow down in the hilly area so that there are no effective dam sites as described in 6.3.1, therefore, the river improvement and retarding basin are to be considered as the flood control facilities to flow down design discharge safely.

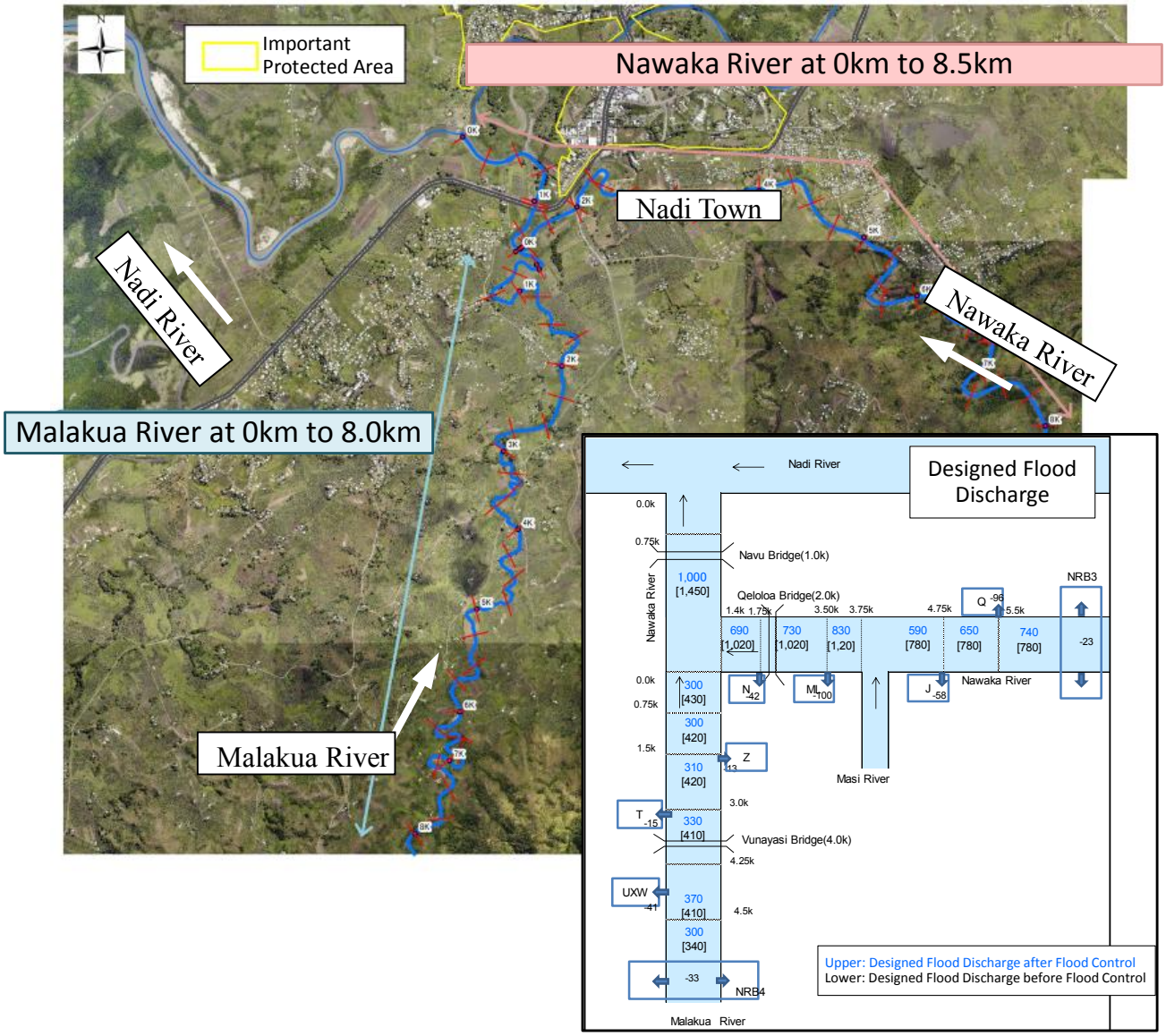


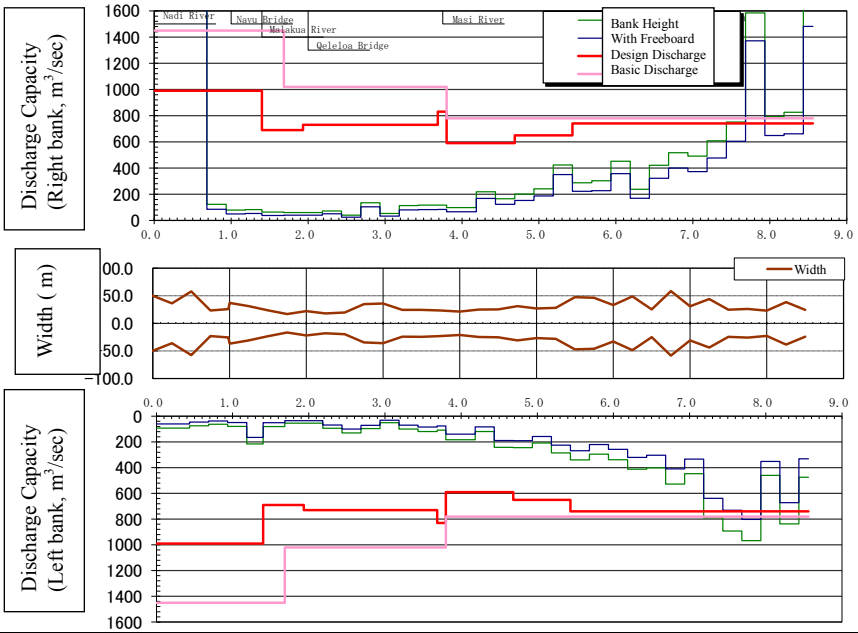
Figure 7-11 Design Flood Discharge in Tributaries (draft)

7.6.2 River Improvement

The present discharge capacity of tributaries is as shown in Figure 7-12. The present discharge capacity is insufficient compared the design discharge so that the appropriate river improvement is required.

流下能力図

Nawaka River



Malakua River

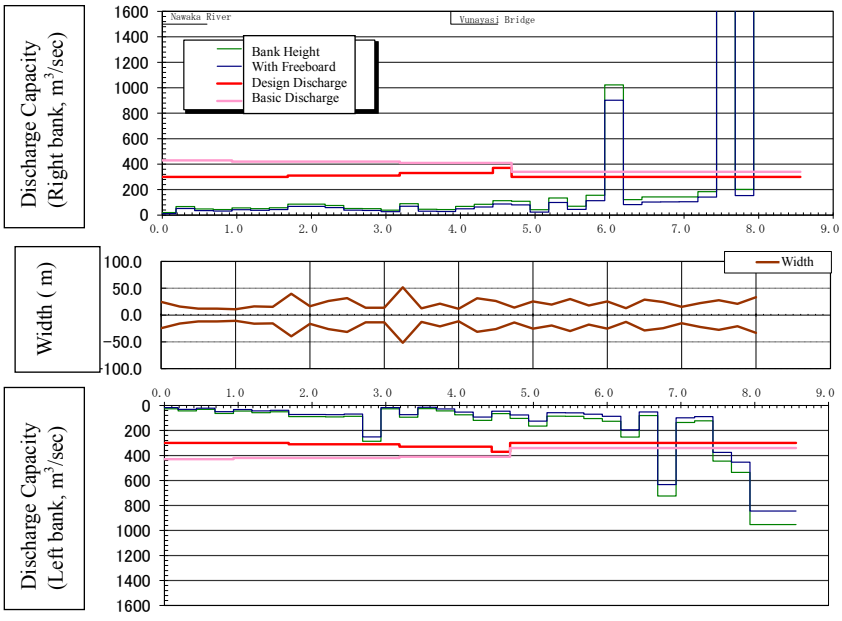
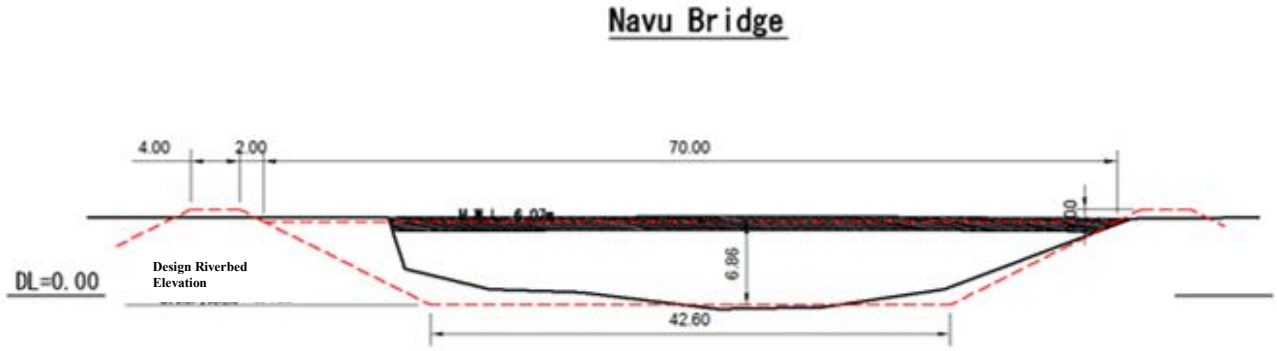


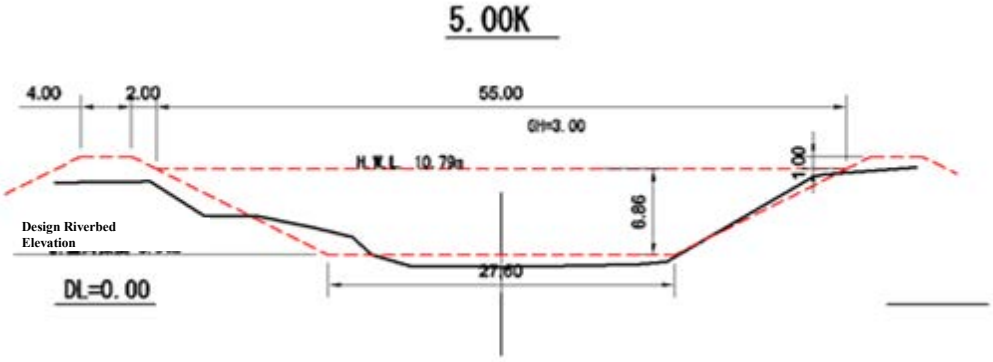
Figure 7-12 Discharge Capacity of Tributaries

The planned cross sections of tributaries are as shown in Figure 7-13.

Nawaka River：0km～Malakua River Confluence Point



Nawaka river：Malakua River Confluence Point～8.5km



Malakua River：Nawaka River Confluence Point～8.0km

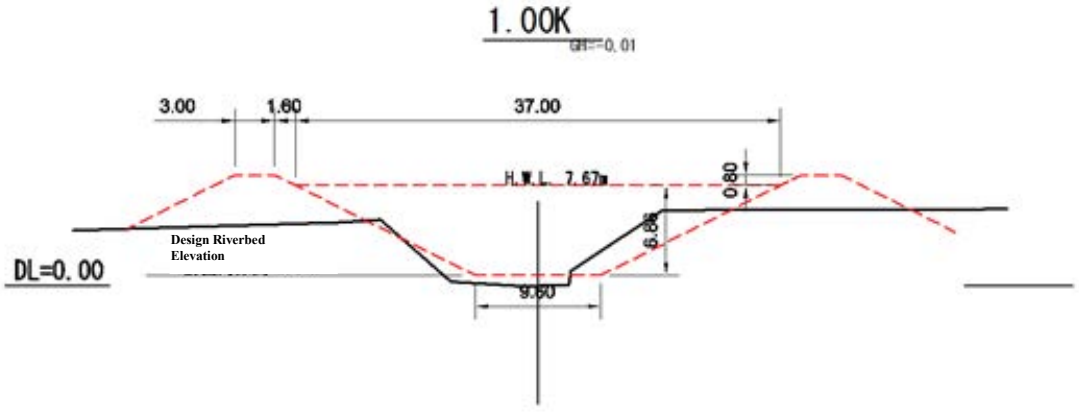
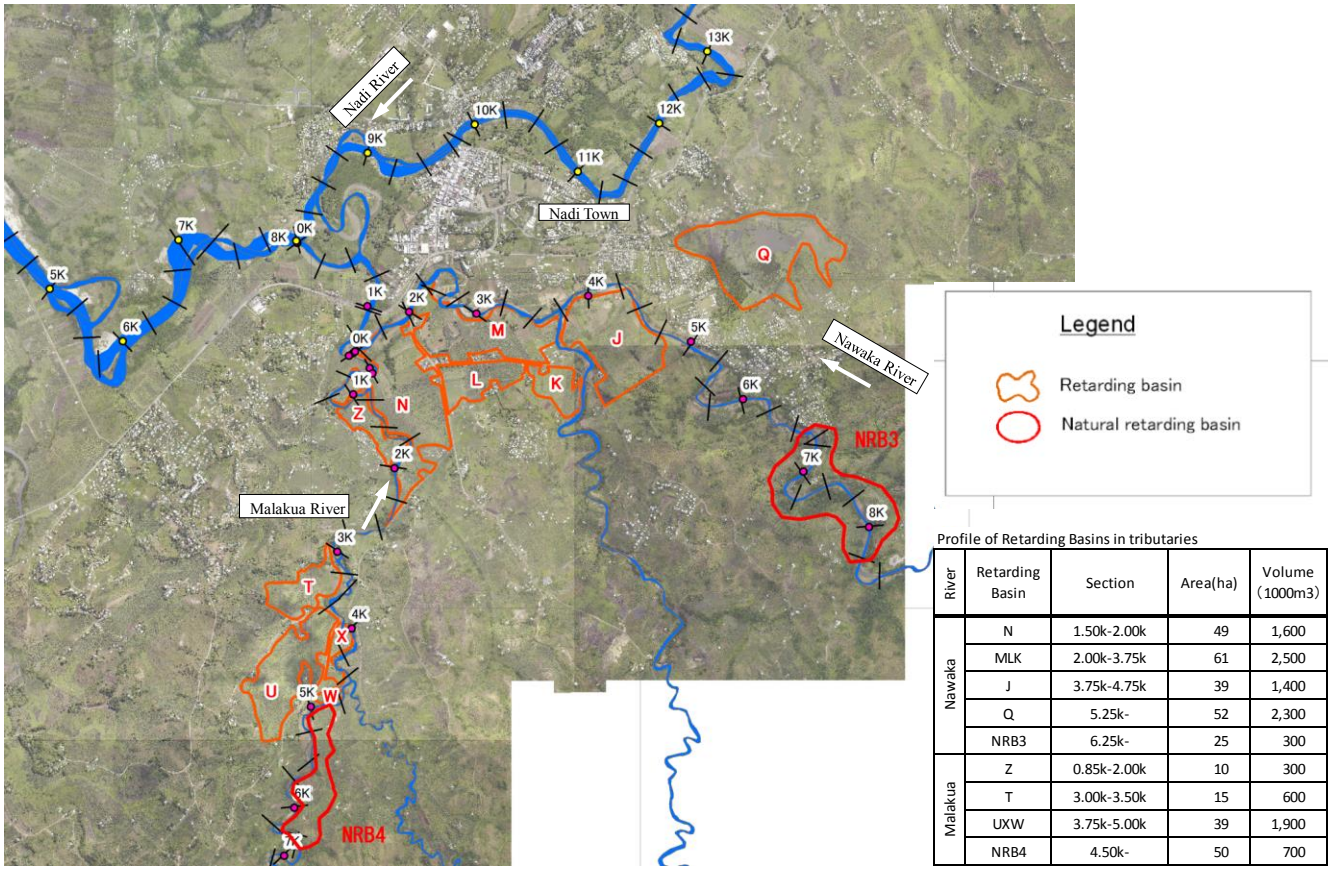


Figure 7-13　Present Cross Section (solid line) and Planned Cross Section (broken line)

7.6.3 Layout of Retarding Basins

The layout of retarding basins in the tributaries of Nawaka and Malakua River is as shown in Figure 7-14.

Those retarding basins are planned to be able to control design flood discharge considering the results of field investigation, topographic conditions, inundation conditions (natural retarding basin; usually inundated area in flooding), land use, asset and existing infrastructures such as housing and road and so on.
The preliminary examination of retarding basin is described in 6.3.2.



Profile of Retarding Basins in tributaries

River	Retarding Basin	Section	Area(ha)	Volume (1000m3)
Nawaka	N	1.50k-2.00k	49	1,600
	MLK	2.00k-3.75k	61	2,500
	J	3.75k-4.75k	39	1,400
	Q	5.25k-	52	2,300
	NRB3	6.25k-	25	300
Malakua	Z	0.85k-2.00k	10	300
	T	3.00k-3.50k	15	600
	UXW	3.75k-5.00k	39	1,900
	NRB4	4.50k-	50	700

Figure 7-14 Layout of Retarding Basins

The retarding basin Q is not located adjacent of Nawaka River so that the headrace channel and drainage channel are required between the retarding basin and Nawaka River, of which root is as shown Figure 7-15.

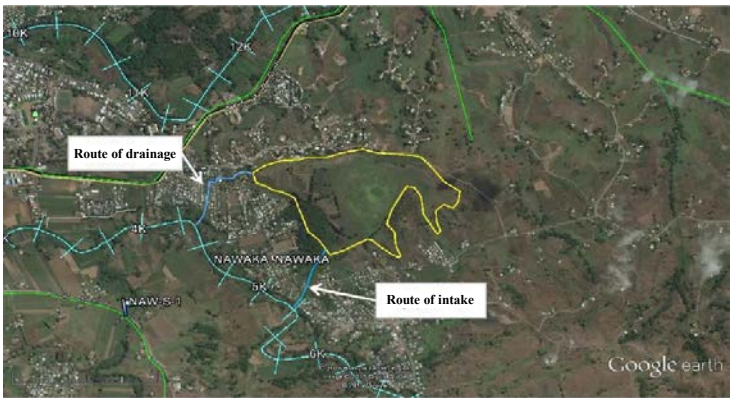
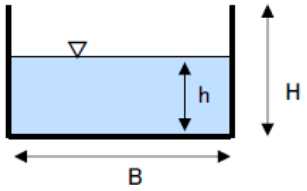


Figure 7-15 Headrace and Drainage Channel of Retarding Basin Q

The capacity of headrace and drainage channel is determined depending on the maximum regulating discharge and topographic gradient of each root. The calculation results by uniform flow calculation are as shown below.

Design discharge of headrace channel: Q=91m3/s
Cross section of headrace channel: B11.0m×H4.4m L=420m I=1/618

Design discharge of drainage channel: Q=29.4m3/s
Cross section of drainage channel: B5.0m×H2.5m L=633m I=1/730



■ **Result of uniform flow calculation**

Item	Conditions										Design Discharge Qk(m3/s)
	Width B(m)	Height H(m)	Water Depth h(m)	Area A(m2)	Wetted Perimeter S(m)	Hydraulic radius R(m)	Gradient I	Roughness Coefficient n	Velocity V(m/s)	Discharge Q(m3/s)	
Intake	11.000	4.400	3.300	36.3000	17.600	2.0625	0.0016	0.025	2.607	94.639	91.0
Drainage	5.000	2.800	2.500	12.5000	10.000	1.2500	0.0027	0.025	2.407	30.082	29.4

$A=B\cdot h$ $V=1/n\cdot R^{2/3}\cdot I^{1/2}$
$S=B+2\cdot h$ $Q=A\cdot V$
$R=A/S$

■ **Setting of bed slope of intake**

Location	Distance	Elevation (m)	Length (m)	Height Difference (m)	Bed slope
Retarding basin Q	0	6.700	–	–	–
Nawaka River 5.2k	420	7.380	420.000	0.680	1/618

■ **Setting of bed slope of drainage**

Location	Distance	Elevation (m)	Length (m)	Height Difference (m)	Bed slope
Nawaka River 4.35k	0	5.000	–	–	–
Retarding basin Q	633	6.700	633.000	1.700	1/372

The shape and cross section area of headrace and drainage channel will be determined in detail in the detail design.

7.7 Flood Control Plan and Optimal Combination of Counter Measures

7.7.1 Final Selection of Flood Control Measure in Middle Stream Section

The following two (2) alternatives of Master Plan for the flood Control Measure were proposed in the previous 7.2.

- ✓ Combination-1: Middle stream river improvement (for design discharge of 1400m^3/s)＋Dam (NAD-3)＋ Retarding basins [Downstream + Upstream]
- ✓ Combination-2：Middle stream river improvement (for design discharge of 700m^3/s)＋Dam (NAD-3)＋ Retarding basins [Downstream + Upstream] + Diversion channel route- 2

The above alternatives are distinguished with flood control measure in the middle stream section of Nadi River. They are the river channel widening is in Combination-1 and the diversion channel is in Combination-2
In this clause the flood control measures in the middle stream section are focused and compared from view point of flood control effect, social environmental impact, cost, opinions of stake holders and residents and so on. And final selection of two alternatives will be carried out.

(1) Alternatives of Flood Control Measure

1) River Channel Widening

This alternative is to widen the river channel from 5.75km point to Back Road Bridge (18.75km) so that the design discharge of 1,400m^3/sec is able to flow down safely.

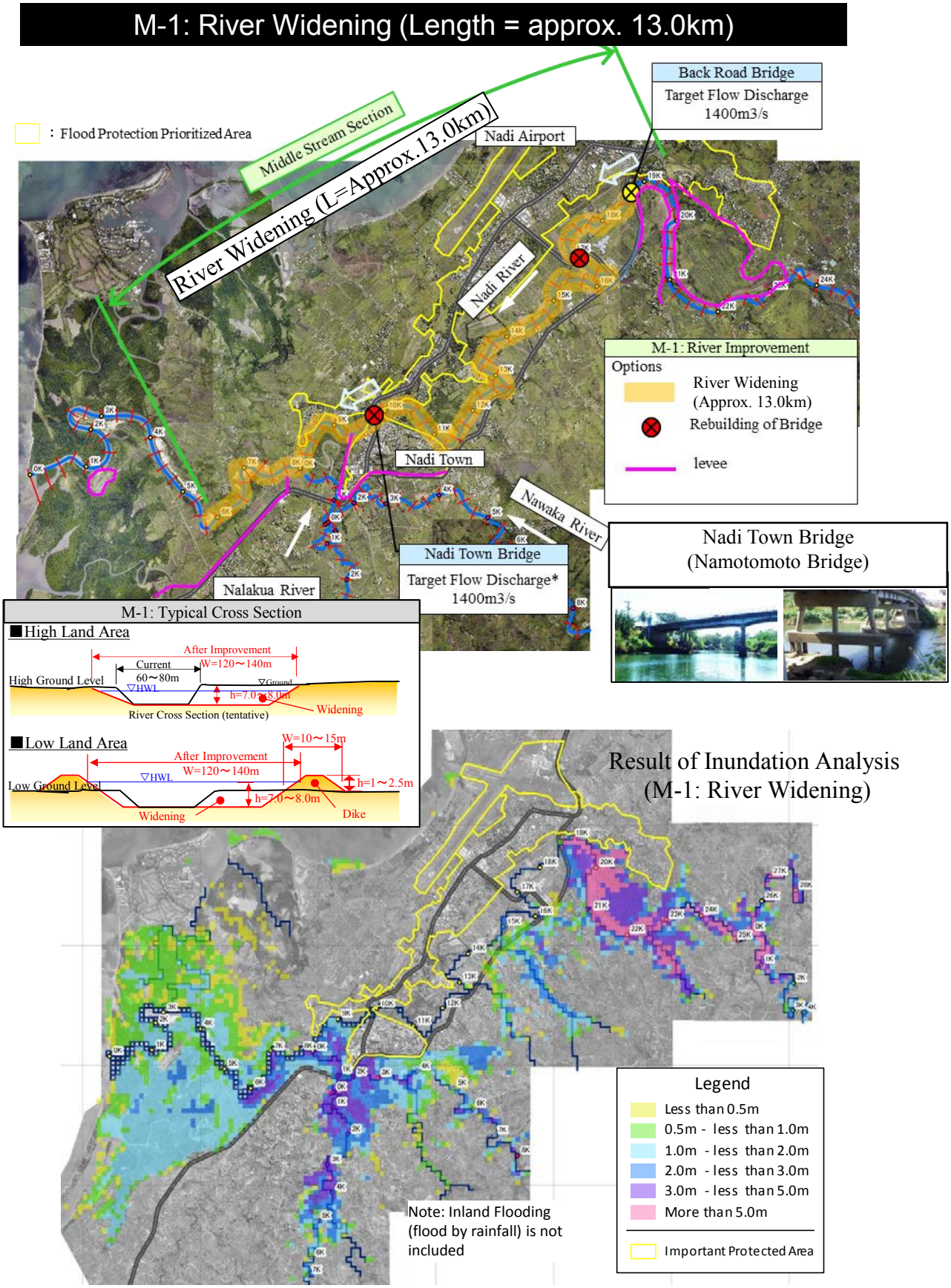
The river channel widening is to be implemented until the area where the inundation will not occur in the important protected area at the downstream end (5.75km point of main stream) and until the Back Road Bridge (18.75km point) at the upstream end, of which bridge section will be a critical point for design discharge.

The layout of the river channel widening and the inundation condition after widening are as shown in Figure 7-16.

2) Diversion Channel

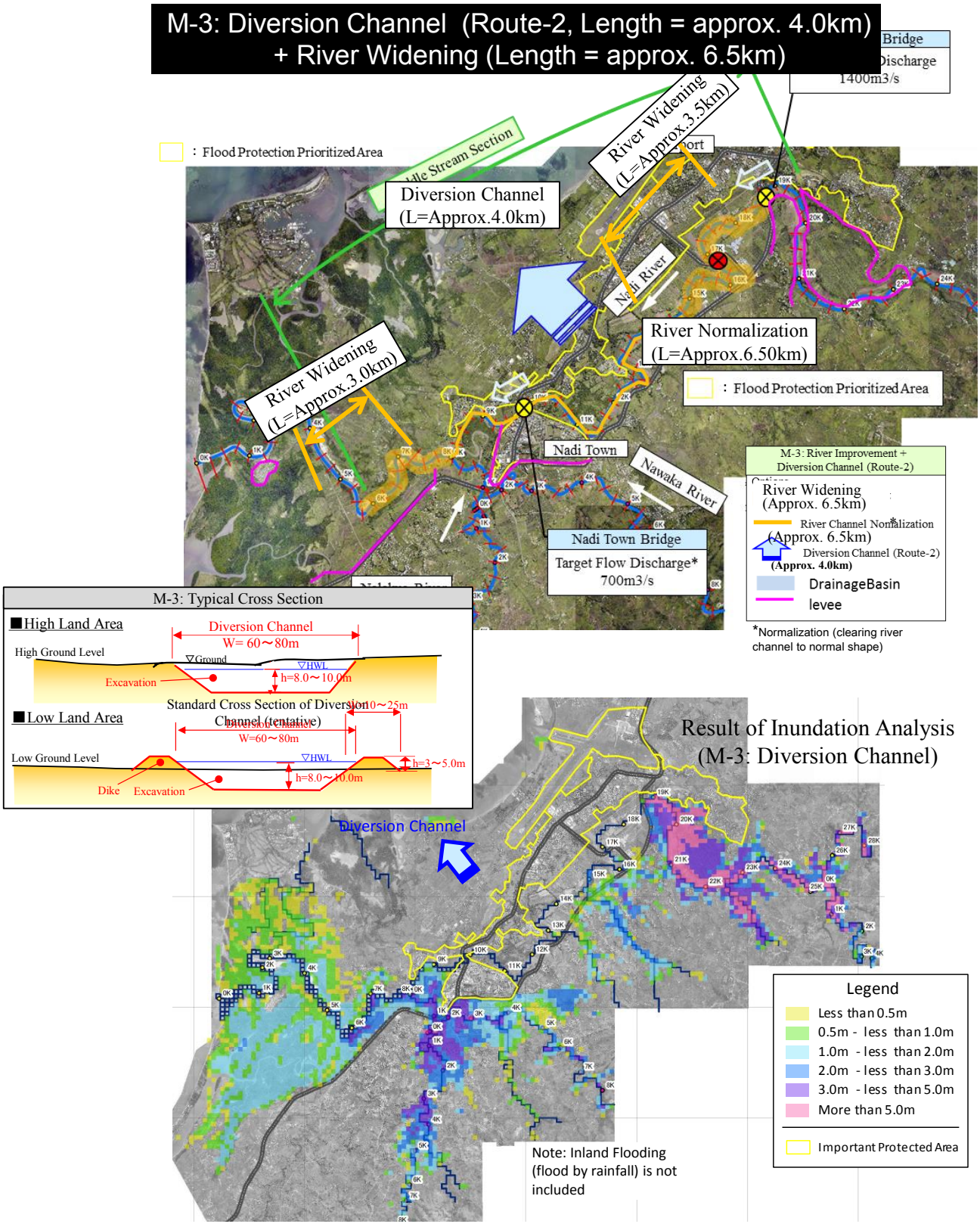
This alternative is to construct the diversion channel from 14km point of Nadi River main stream to Nadi Bay and the total design discharge is divided to the river mouth and Nadi Bay by 700m^3/sec each.

The layout of diversion channel and the inundation condition after implementing the diversion channel are as shown in Figure 7-17.



Source: JICA Study Team

Figure 7-16 River Channel Widening in Middle Stream Section



Source: JICA Study Team

Figure 7-17 Diversion Channel in Middle Stream Section

In the above both alternatives, in addition to the river widening and the diversion channel, the upstream retarding basin A and B, surrounding dike around Nadi town and the ring dike in the downstream area, short-cut in the tributaries are included. Necessity of such flood control structures are described as shown below.

< The upstream retarding basin A and B>

When the flood control measures in the middle stream is implemented as the priority project, the upstream dam proposed in the Master Plan is not yet completed so that the non-regulated flood discharge flow down into the middle stream section causing inundation in that area, therefore the retarding basins A and B are to be implemented for regulation of such flood discharge.

< The surrounding dike around Nadi town>

When the priority project is implemented, the river improvement in the middle stream is carried out before the downstream in order to protect important protected area, however, it is not possible to prevent the inundation of those area with the countermeasures in the Master Plan. Therefore the surrounding dike around Nadi town is required to protect the important area at the time of the priority project.

< The ring dike in the downstream area>

After the implementation of the abovementioned flood control measures, the inundation is prevented in the important area, however, due to the river widening in the middle stream, the inundation depth in downstream area increases (hereafter called “negative impact”), therefore as countermeasures to the negative impact, the ring dike in the downstream area is required.

< The short-cut in the tributaries >

And when the priority project is implemented, the river improvement and retarding basins in tributaries which are established in the Master Plan are not yet implemented so that the negative impact occurs in the tributaries due to stagnation of flood discharge from Nawaka and Mlakua Rivers at the confluence point of Nadi River and influence by the surrounding dike around Nadi town, therefore in order to reduce such negative impact, the short -cut in the tributaries is required.

The detail of such necessary structures (refer to Table7-4) is examined in 7.7.3 Selection of Priority Project, after the final flood control measures in the middle stream section is selected.

Table 7-4 Necessary Structures in Middle Stream Section in Implementation of Priority Project

Additional Structures	Necessity
Upstream Retarding Basin A&B	✓ To regulate the flood discharge from the upstream
Surrounding dike around Nadi town	✓ To prevent a part of Nadi town from inundation
Ring dike in downstream area	✓ To prevent community located in candidate retarding basin in downstream area (Moala village) from inundation.
Short cut in tributaries	✓ To reduce the negative impact in tributaries.

(2) Comparison of Alternative Plan of Flood Control in Middle Stream Section

1) Comparison of Alternatives

The river channel widening (M-1) and the Diversion channel (M-3) are compared from view point of influence to the existing public infrastructure, flood control effect, construction period, maintenance management, social influence such as land acquisition area and relocation of housing, natural environmental impact to seashore, economical benefit. The results of comparison is described below and shown in Table 7-5～Table 7-7. The final selection of the alternatives are carried out based on the above comparison results, and opinion of residents and JCC (Joint Coordination Committee) of Fiji side.

a) Influence to Existing Public Infrastructure

As to rebuilding bridges, two (2) bridges in the river widening (M-1)(Nadi town bridge, Old Queens bridge), and one (1) bridge in the diversion channel (M-3) (Old Queens bridges) are required to be rebuilt. On the other hand two (2) bridges are required to be newly constructed in the diversion channel (M-3).

b) Flood Control Effect

The both alternatives (M-1 and M-3) have same good flood control effect.

c) Construction Period

The river widening (M-1) requires 4～5 years period because the construction work is limited in dry season. The diversion channel (M-3) requires 3～4 years which is shorter than M-1 by one year because construction work of M-3 can be carried out in even in rainy season.

d) Maintenance

Dredging of river channel and maintenance of bank protection and river structure will be necessary in the both alternatives (M-2 and M-3), however the diversion channel will be also maintained in the alternative of diversion channel (M-3)

e) Social Influence

Land acquisition area is 118ha in the river widening (M-1) of which break down is Native Land：79ha、Free Hold Land：39ha. And that of the diversion channel (M-3) is 122ha of which break down is Native Land：60ha、Free Hold Land：62ha. The areas are rough estimation in the comparison and reviewed in the Feasibility Study.

Number of relocation of housing is 28 in the river widening (M-1) and 40 in the diversion channel (M-3). The number of housing is rough estimation in the comparison and reviewed in the Feasibility Study.

f) Influence to Natural Environment(Influence to Seashore)

As to the influence to natural environment, the comparison of influence to seashore topography which is likely to be large is examined by the seashore topographic analysis. The results of analysis is as shown in Table 7-7.

In the river widening (M-1), after 10 years later although the seashore at mouth of Nadi River(C1 area in Table 7-7) will expand to seaside due to sediment discharge from Nadi River, the difference between with river widening

and without it (at present) will be nil. Although the Nadi Bay (C2 area in Table 7-7) will slightly expand to seaside, the difference between with and without is not observed. The west seashore of Denarau area(C3 area in Table 7-7) and the north seashore (C4 area in Table 7-7) have the tendency of erosion by tidal flow and wave and the erosion will be continued after 10 years later, however the difference between with and without will be nil. Therefore the impact of the river widening (M-1) to seashore topography is likely to be small.

In the diversion channel (M-3) , after 10 years later the seashore at mouth of Nadi River(C1 area in Table 7-7) will expand to seaside due to sediment discharge from Nadi River, the difference between with diversion channel and without it (at present) will be remarkable. After implementation of the diversion channel, the magnitude of seashore expanding at the river mouth will be reduced due to decrease of sediment discharge from Nadi River. The difference of seashore topography is remarkable at the outlet of diversion channel to Nadi Bay (C2 area in Table 7-7), the seashore will expand more to the seaside after implementation of the diversion channel. The west seashore (C3 area in Table 7-7) and the north seashore (C4 area in Table 7-7) of Denarau area have the tendency of erosion by tidal flow and wave and the erosion will be continued after 10 years later, however the difference between with and without will be nil of which tendency is same as the river widening (M-1). Therefore in the diversion channel (M-3), the future seashore topography change is remarkable between with diversion channel and without it, and the difference will occur remarkably in the mouth of Nadi River (C1 area in Table 7-7) where the sediment discharge will be reduced due to the diversion channel construction and at the outlet of diversion channel in Nadi Bay where the sediment will be newly supplied.
In addition, the west shore (C3 district in Table 7 7) and the north shore (C4 district in Table 7 7) of Denarau area have the tendency of erosion by tidal flow and wave and the erosion will be continued for 10 years later. This trend is believed to be going on weather flood control measures (the river widening and diversion channel) are implemented or not.

The detail analysis of seashore topography is as shown in Chapter 10 Seasore.

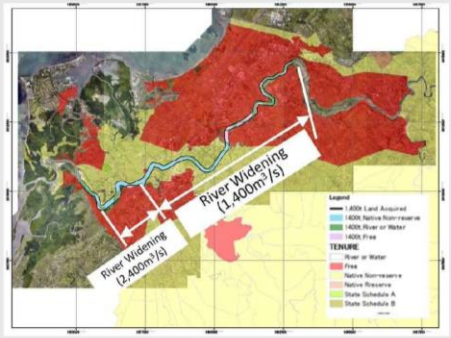
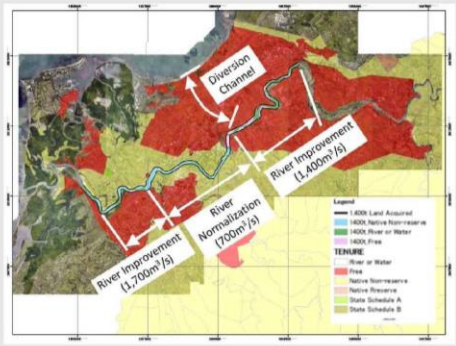
g) Economic Efficiency

The economic efficiency is almost same in the both alternatives of the river widening (M-1) and the diversion channel (M-3).

Table 7-5 Comparison between River Widening (M-1) and Diversion Channel (M-3) in Middle Stream Section (1/3)

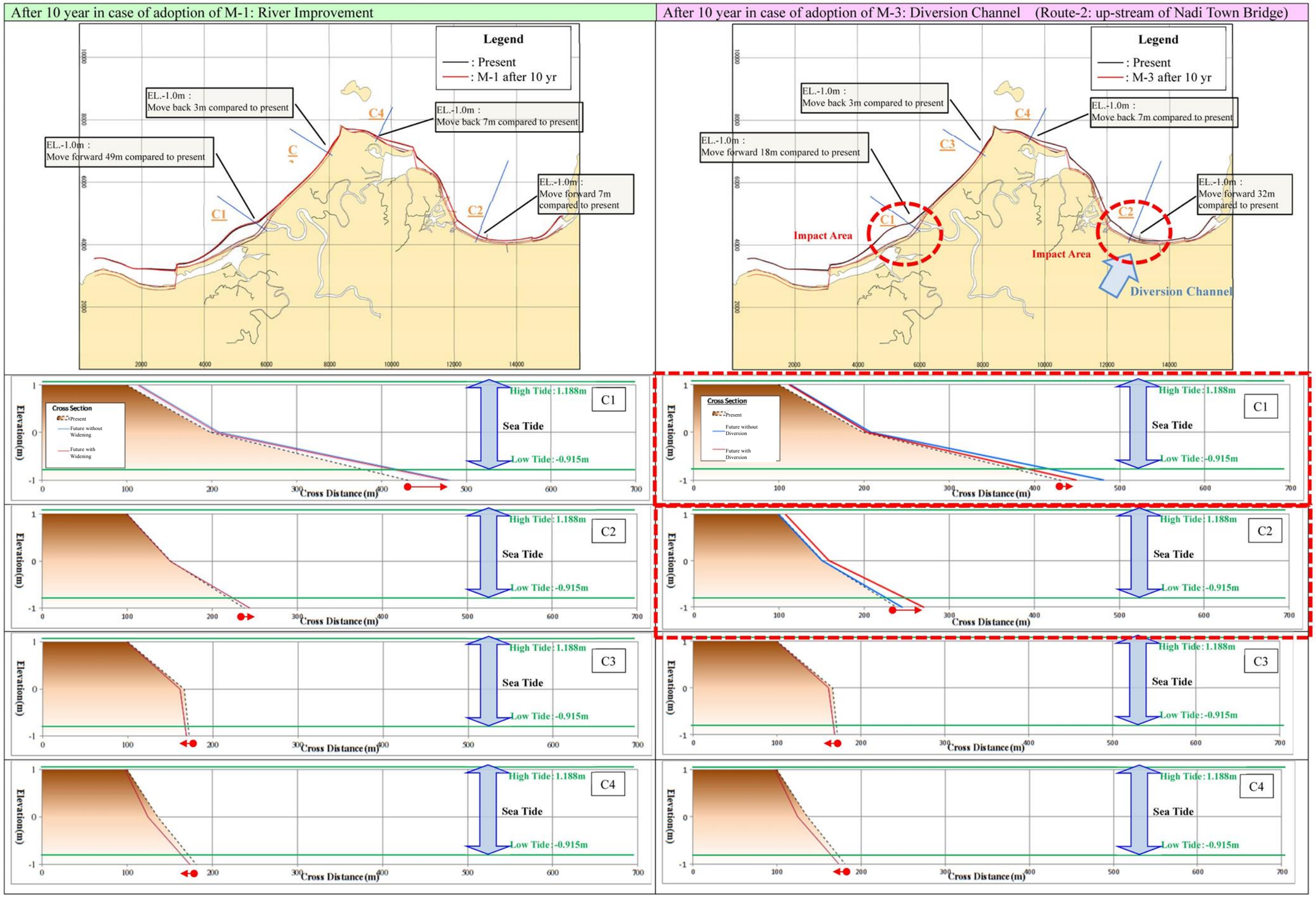
Aspect		M-1 (River Widening)	M-3 (Diversion)
Main Items		✓ River Channel Widening (L=Approx.13km)	✓ Diversion Channel (Route-2) (L=Approx.4km) ✓ River Channel Widening(L=Approx.6.5km) ✓ River Channel Normalization (L=Approx.6.5km)
Affect to Existing Public Facilities		✓ Rebuilding of bridge(2): ・Nadi Town Bridge (Namotomoto) (L=Approx.140m) ・Old Queens Road Bridge (L=Approx.140m)	✓ Rebuilding of bridge(1): ・Old Queens Road Bridge (L=Approx.140m) ✓ New Construction of bridge(2) over diversion: ・Queens Road (L=Approx.80m) ・Bypass Road (under construction) (L=Approx.80m)
Flood Control safety degree (Effectiveness)	Reduced Inundated Area in Important Protected Area by Priority Project	Good	Good
		A=330ha→0ha	A=330ha→0ha
	Reduced Inundated Area in a whole river basin by Priority Project	Good	Good
		5,129ha→3,158ha (-38%)	5,129ha→3,006ha (-41%)
Construction Period		4-5years	3-4 years
Sustainability (O&M in the future)		Medium	Medium
		(Necessity of Maintenance Dredging for Nadi River)	(Necessity of Maintenance Dredging for Nadi River and Diversion)

Table 7-6 Comparison between River Widening (M-1) and Diversion Channel (M-3) in Middle Stream Section (2/3)

Aspect		M-1 (River Improvement)	M-3 (Diversion)
Social Impact	Land Acquisition	Native Land : 79ha Free Hold Land: 39ha Total : 118ha  Landholding Map in the Project area (Land Data Source: TLTB, 2014)	Native Land : 60ha Free Hold Land: 62ha Total : 122ha  Landholding Map in the Project area (Land Data Source: TLTB, 2014)
	Number of House RelocationS	28 houses	40 houses
Environmental Impact (Shoreline)		Although influence of river widening is considered, it is assumed that shoreline at Nadi river mouth will not be changed so much from current profile.	Outflow discharge with sediment from diversion channel and Nadi river will be effected to future shoreline after large flood occurrences. The numerical analysis will be conducted and the result will be expressed in next stage.
Cost Ratio (Based on rough cost estimate)		1.00	0.98 (in case that cost of M-1 is 1.00)
Comprehensive Evaluation ○ : Acceptable △ : Acceptable with conditions			
Reasons for Selection and Non Selection			3

※ The land acquisition area and number of relocation housing are rough estimation in the comparison which will be revised in detail in the Feasibility Study.

Table 7-7 Comparison between River Widening (M-1) and Diversion Channel (M-3) in Middle Stream Section (Impact on Seashore) (3/3)



2) Opinions of Residents and Stakeholders

The opinions of residents and stakeholders for the study results were collected in the Public Consultation held on June 17, 2015 in Nadi town. The supplement explanation of the study results were carried out to the related agency of the Fiji Government.

The collected opinion in the Public Consultation and the governmental agencies are as shown in Table 7-8 and Table 7-9 and Figure 7-18 respectively.

Table 7-8 Opinions of Residents in Public Consultation

Participant's opinions	Issues	River Widening	River Diversion
1	More information on rainfall and issues of flooding in Nadi is required. Need to address drainage issue with all the developments occurring was mentioned.	Information such as inundation of river and rise in sea level during cyclone are needed to be provided.	
2	Decision would be made considering the public consultation, not as a formality. Asking for some case scenarios of flood countermeasures in other countries which JICA Study Team was involved.		
3	Solution should address to improve flow out to sea.	River widening should be extended to the river mouth.	Possible solution is to divert flood all the way to sea.
4	Development Potential	It will create opportunities for recreation and tourism development as in China for similar works.	Chinese Hotel investor do not support because the acquired land will be affected. It will cause environment impacts of construction and debris into Wailoaloa beach during flood.
5	Information on reason and cause of flooding are required. People should be aware that the Nawaka River also contributes to flooding.	(No comment)	It has low priority because flood damage is also caused by the Nawaka River.
6	Proposal of shorten the Nadi River from below Nadi Bridge to Moala Village.	To consider widen and shorten river length out to sea.	(No comment)
7	Which option is more effective?	Effectiveness and construction cost are almost the same.	
8	Question about risks of extraordinary flood	Support of river widening and shortening because damage by extraordinary flood seems to be smaller than diversion plan.	There is no guarantee for future larger floods than target scale. Diversion will probably cause problems in areas where no flooding larger than widening plan

			when extraordinary flood occurs.
9	Mataqali Land	(No comment)	Mataqali Land representative supports this plan because Mataqali land will not be affected.
10	Developments, Cost factor and land acquisition should be considered. Any options cannot avoid all floods or disaster.	Support of widening with bank protection and dykes. It has potential use for recreation and tourism developments.	It will be more expensive.
11	Drainage system of Denerau Road is not good enough. People purchasing land are raising its level which is contributing to the change in drainage patterns.	(No comment)	It has negative impact on tourism development in the Wailoaloa area. Silting coming from the diversion will affect the Denarau Marina. Salinity intrusion and effect on groundwater should be taken into consideration.
12	There is a possibility to use material to raise banks and create lakes for storage of the flood waters	Support of shortening and widening river to the mouth.	(No comment)
13	Consultation will provide support to the Study Team and the proposed options. Plea to land owners for collective understanding and not self-interests. Both options will have same cost and effectiveness.	It will support the goal to develop Nadi City. It will also provide recreational and development potential, land value improvement raise status and value.	It will be a scar on the landscape and will be dry most of the time and only in use when a flood occurs. It will also cause seawater intrusion and have an effect on groundwater.
14	Interested in the new Nadi Bridge which will be rebuild.	Support of widening and also considering relocation of the Nadi Bridge.	
15	Dykes near the Namulomulo Bridge are worn out and other side is covered with sand. Pollution and blockage of creek with rubbish should be considered.	(No comment)	(No comment)

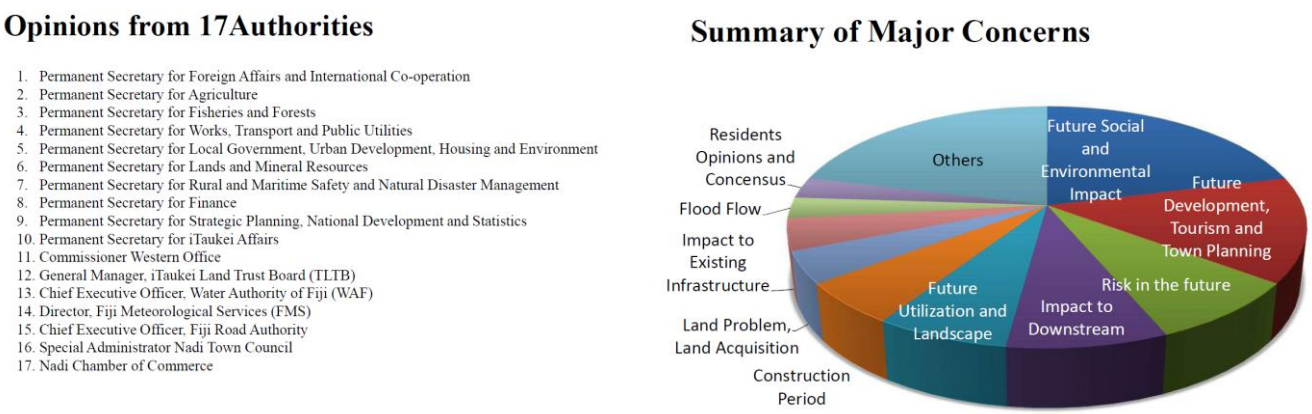


Figure 7-17 Diagram of Collected Opinions from Governmental Agencies

Table 7-9 Collected Opinions from Governmental Agencies

Aspect	M-1 (River Widening)	M-3 (Diversion)
Positive opinion	<Social and Environmental Impact> ● The social and environmental impact is less than the Diversion. ● Only Moala Village will be impacted with the river widening project. To lessen this impact on Moala Village, retaining wall (actually ring dike) will be built. ● Number of House Relocations is less. ● All projects will be approved after consideration has been made on the social and environmental impacts. (Government Policy for all capital projects) ● River widening is more natural than the Diversion. <Development, Tourism and Town Planning> ● It will create new values to river bank properties and promote new developments, residential & commercial ● It will open up opportunities to create new tourism, recreational and beautification concepts to Nadi Town & communities ● It will enhance Nadi Town's visions of creating a "New City" with the new river and bridge as its development features. <Residents Opinion, Consensus> ● River Widening seems to be easy to be accepted by the people along the river because they are damaged by flood many times. ● It keeps the general population demographics in existing communities. <Flood Flows>	<Flood Flows> ● Flood is diverted fast to sea before flowing into central area of Nadi Town without much interruption. <Nature restoration> ● If the old river channel route that is dried up near McDonald's is used, it will return back to its past natural situation. <Construction Period> ● Diversion Channel construction period shorter than river widening.

	● It will ease current erratic flow of river <Construction, Disposal> ● The fill material gained from the river excavations can be used to enhance current low ground in villages & communities to be utilized as farmland or new development.	
Negative opinion and Concerned Issues	<Impact to Down Stream, Measures in Downstream> ● Widening does not reach up to the sea. Therefore, there is risk that flood will accumulate at the end point of widening, near Moala Village and spread around town, in particular to Moala Village and surrounding flat lands. ● Current river mouth is narrow	<Social and Environmental Impact> ● With the diversion project, new route/channel has to be created which will have greater social and environmental impacts. ● 40houses will be relocated and other problems like traffic congestion will occur due to the construction of the new diversion channel in the area. ● Seacoast line will be changed at Nadi Bay and River mouth. In addition, potential for development utilization will be drastically changed at Nadi Bay. <Risk in the future> ● If an overflow occurs over the diversion channel from a flood greater than its capacity, this will cause more disaster. In addition, there is a possibility that the airport will be inundated. ● There is a risk for children to drown when flood flows in diversion channel suddenly like flash flood. <Development, Tourism and Town Planning> ● The construction of new diversion channel will have an effect on the current hotel developments in the area. ● Value of assets near Diversion will be decreased. ● Extensive negotiation with current developments will be required. <Utilization and Landscape> ● Nadi Bay is good public beach and sea water is clean because mud rarely flows into the bay. ● The discharge of flood water & debris into Wailoaloa will further damage the ecosystems and the name Wailoaloa (Black Water) will be a negative reality, as visitors fly into Nadi and view this reverse of nature. From natural blue water to black. ● Diversion channel is artificial and create a “major” scar in the natural landscape. ● As the channel will be empty most of the time, high risk of its use as a dumping ground for garbage.

		● The whole of the Wailoaloa Bay Tourism activity and potentials to be as dynamic as Denarau will be affected. <Environment> ● As Salt water will enter from the sea side exit point, this water will permeate into the soils and change/harm the groundwater dynamics, flora and fauna. <Construction> ● New bridges will need to be built at a high cost.

3) Final Selection of Flood Control Alternatives

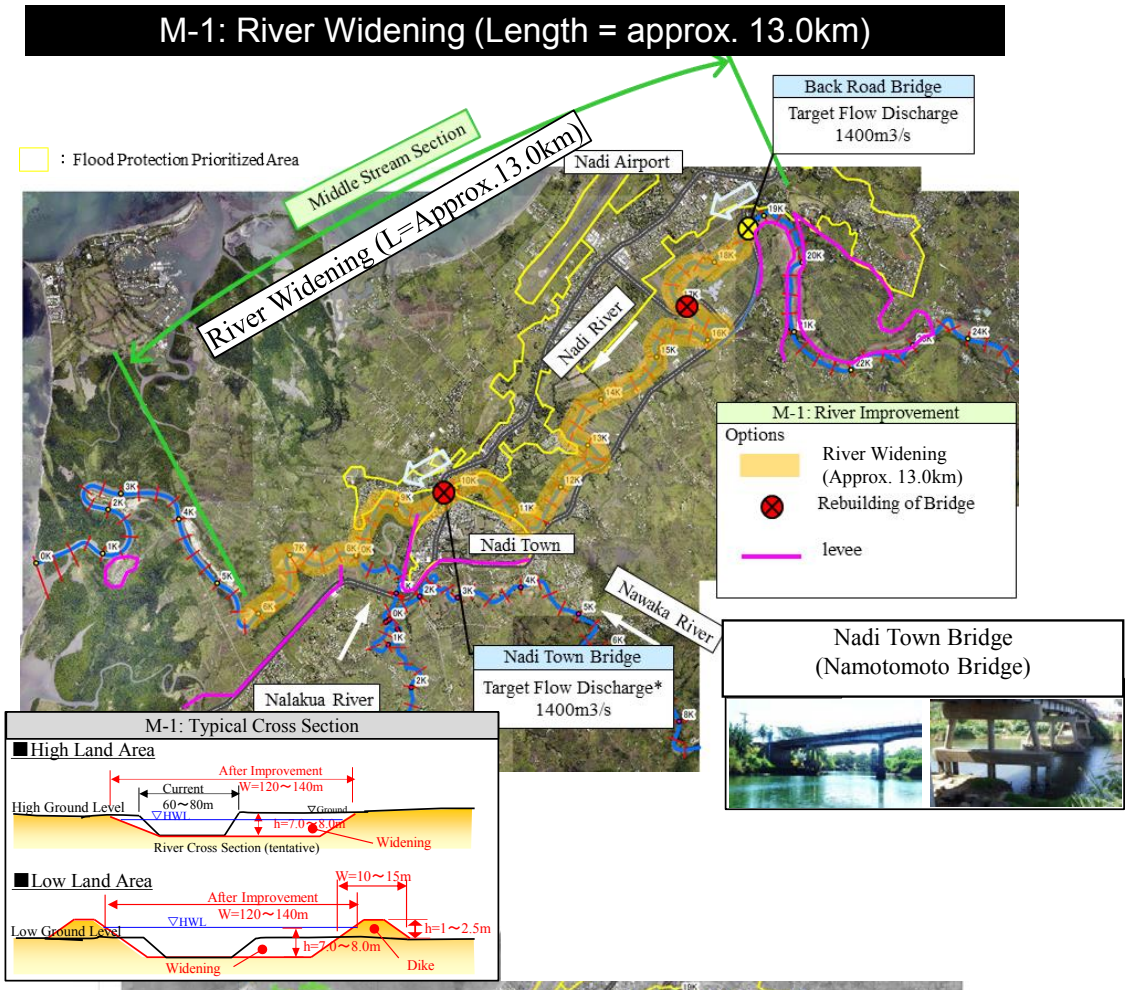
The flood control plan was finally selected in 3rd JCC (Joint Coordination Committee) held in Suva on June 30, 2015 based on the opinion of residents and the governmental agencies. The recommendations of JCC members are as shown in Table 7-10. And the river widening (M-1) was finally selected.

Table 7-10 Recommendations of Governmental Agencies

	JCC Member	Support
1	Permanent Secretary for Foreign Affairs and International Co-operation	M-1: Widening
2	Permanent Secretary for Agriculture	M-1: Widening
3	Permanent Secretary for Fisheries and Forests	-
4	Permanent Secretary for Works, Transport and Public Utilities	M-1: Widening
5	Permanent Secretary of Local Government, Urban Development, Housing and Environment	M-1: Widening
6	Permanent Secretary of Lands and Mineral Resources	M-1: Widening
7	Permanent Secretary of Rural and Maritime Safety and Natural Disaster Management	M-1: Widening
8	The Commissioner Western Office	M-1: Widening
9	Permanent Secretary of Finance	M-1: Widening
10	Permanent Secretary Strategic Planning, National Development and Statistics	
11	Permanent Secretary for iTaukei Affairs	-
12	The General Manager iTaukei Land Trust Board (TLTB)	Neutral
13	The Chief Executive Officer, Water Authority of Fiji (WAF)	M-1: Widening
14	The Director, Fiji Meteorological Services (FMS)	-
15	The Chief Executive Officer, Fiji Road Authority	Neutral
16	The Special Administrator Nadi Town Council	M-1: Widening
17	The Nadi Chamber of Commerce	M-1: Widening

(3) Final Flood Control Plan in Middle Stream Section

The layout of the river widening plan in the middle stream section which was finally selected in 3rd JCC is as shown in Figure 7-19.



F **JCC)**

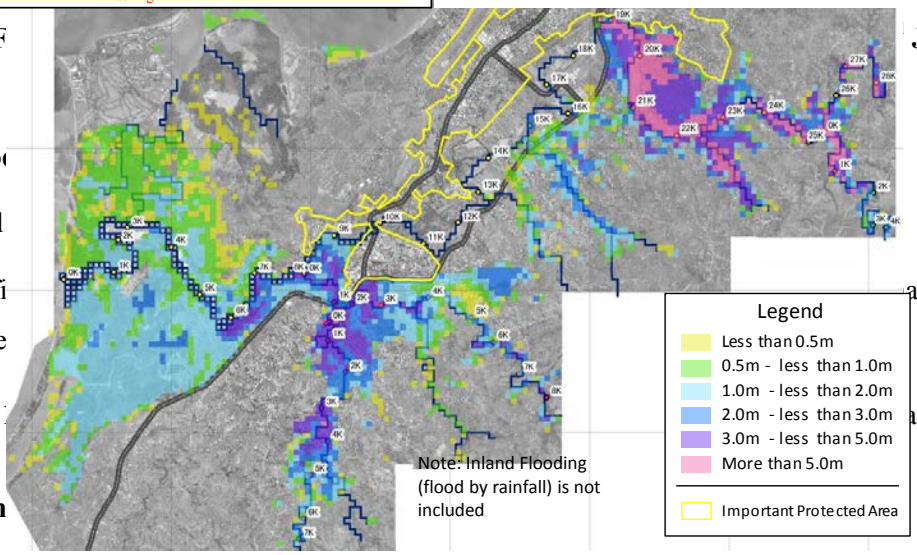
7.7.2 Final Floo

(1) Major Flood

According to the fi al flood control master plan is to be

✓ Combination-1 am】

(2) Design Disch



The design discharge distribution in the Master Plan,,Combination-1 is as shown in Figure 7-20.

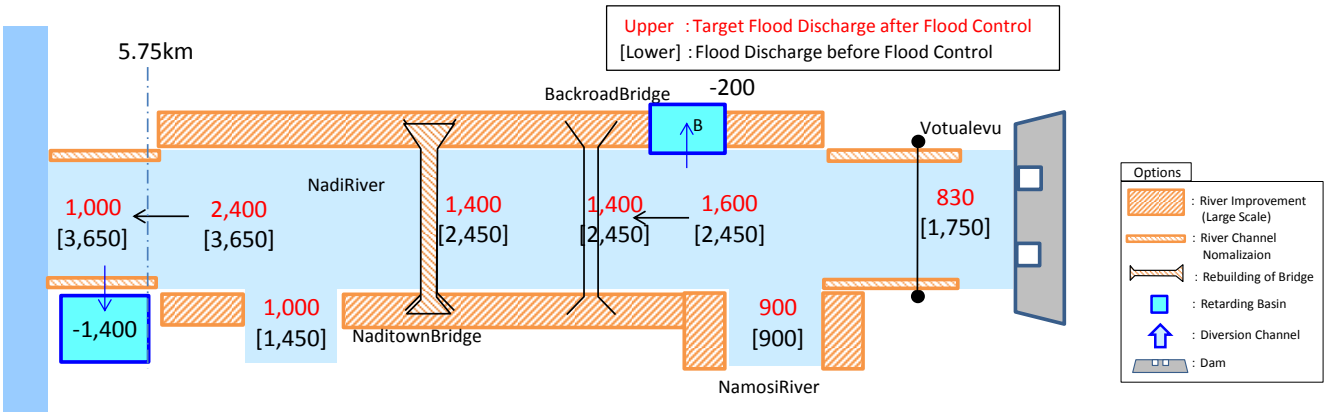


Figure 7-19 Design Discharge Distribution in Final Master Plan

(3) Major Flood Control Structures in Final Master Plan

The major flood control structures in the final master plan are as shown in Figure 7-21 and Table 7-11.

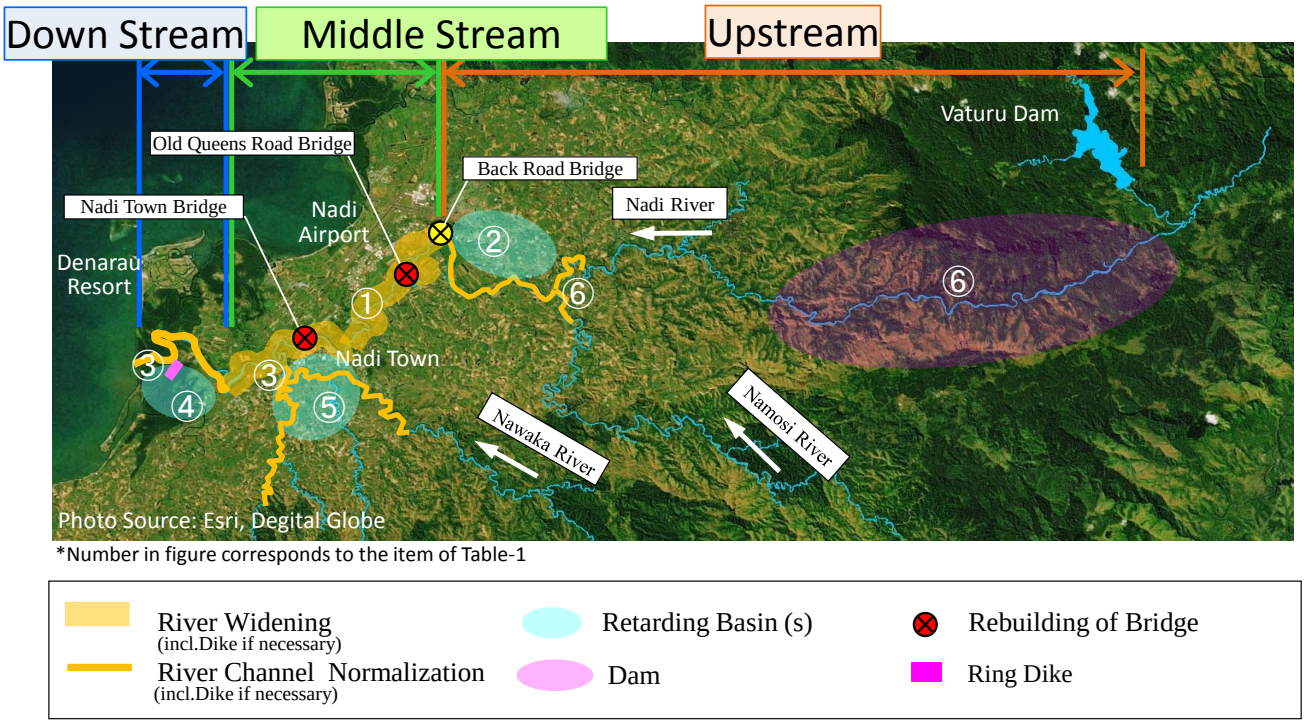


Figure 7-20 Major Flood Control Structures in Final Master Plan

Table 7-11 Major Flood Control Structures in Final Master Plan

Stage		Structural Measures
Structural Measures	Short Term (Priority Project)	① River Widening in middle stream[1)] ② Retarding Basins in up stream ③ Countermeasures for negative impat - Ring Dike - Surrounding Dike - Smoothing of alignment (Shortcut) of the Nawaka River and the Malakua River
	Middle Term	④ Retarding Basin and River Improvement in downstream[2)] ⑤ River Improvement and Retarding Basins in tributaries[3)] ⑥ Dam and river improvement in upstream

1) Rebuilding of 2(two) bridges are included in this component.
2) Dike along the Queen's Road is included in this component.
3) Rebuilding of 4 (four) bridges in tributaries are included in this component.

7.7.3 Selection of Priority Project

(1) Selection of Priority Project

The river widening (M-1) in the middle stream was selected as the priority project among the master plan, which is aiming at prevention of inundation in the important protected area established in [**6.1 Basic Policy in Preliminary Examination of Flood Control Plan**] and which has top priority of implementation.

However when the flood control measures in the middle stream is implemented as the priority project, the upstream dam proposed in the Master Plan is not yet completed so that the non-regulated flood discharge flow down into the middle stream section causing inundation in that area, therefore the retarding basins A and B are to be implemented for regulation of such flood discharge

After the implementation of flood control measures in the middle stream, the inundation is prevented in most of the area, however the inundation in a part of Nadi town which is important protected area is still left and due to the river widening in the middle stream, the inundation depth in downstream area increase a little bit (so called "negative impact"), therefore as countermeasures to the negative impact, surrounding dike around Nadi town and the ring dike in the downstream area are required.

And when the priority project is implemented, the river improvement and retarding basins in tributaries which are established in the Master Plan are not yet implemented so that the negative impact occurs in the tributaries due to stagnation of flood discharge from Nawaka and Mlakua Rivers at the confluence point of Nadi River and influence by the surrounding dike around Nadi town, therefore in order to reduce such negative impact, the short cut in the tributaries is required.

Therefore the flood control measures shown in Table 7-12 are required in addition to the river widening in the priority project. The concrete examination of each measure is described in [(2) Examination of Flood Control Measures in Priority Project].

Table 7-12 Flood Control Structures in Middle Stream Section in Implementation of Priority Project

Structures	Necessity
River Widening	✓ To flow the design flood discharge safely
Upstream Retarding Basin A&B	✓ To regulate the flood discharge from the upstream
Surrounding dike around Nadi town	✓ To prevent a part of Nadi town from inundation
Ring dike in downstream area	✓ To prevent community located in candidate retarding basin in downstream area (Moala village) from inundation.
Short cut in tributaries	✓ To reduce the negative impact in tributaries.

(2) Examination of Flood Control Measures in Priority Project

The flood control measures in the priority project are examined concretely.

1) River widening inMiddle Stream Section

In the priority project the river widening is implemented for the equal scale of design discharge in the master plan, of which occurrence probability is once in 50 years. The river channel plan will be described in [8.2 Planning of River Channel in Main Stream and Tributaries].

2) Upstream Retarding Basins A and B

In the priority project the upstream retarding basins A and B is implemented for the equal scale of design discharge in the master plan, of which occurrence probability is once in 50 years. The retarding basin plan will be described in [8.3 Planning of Retarding Basins in Main Stream and Tributaries].

3) Surrounding Dike around Nadi town

The inundation in a part of Nadi town which is important protected area is still left after completion of river widening in the middle stream due to inundation from tributaries. The surrounding dike around Nandi town is implemented to prevent the residual inundation

The surrounding dike is implemented to prevent inundation to the important protected area as well as to be implemented in advance as a part of the master plan.

The layout of the surrounding dike is to be as shown in Figure 7-22.

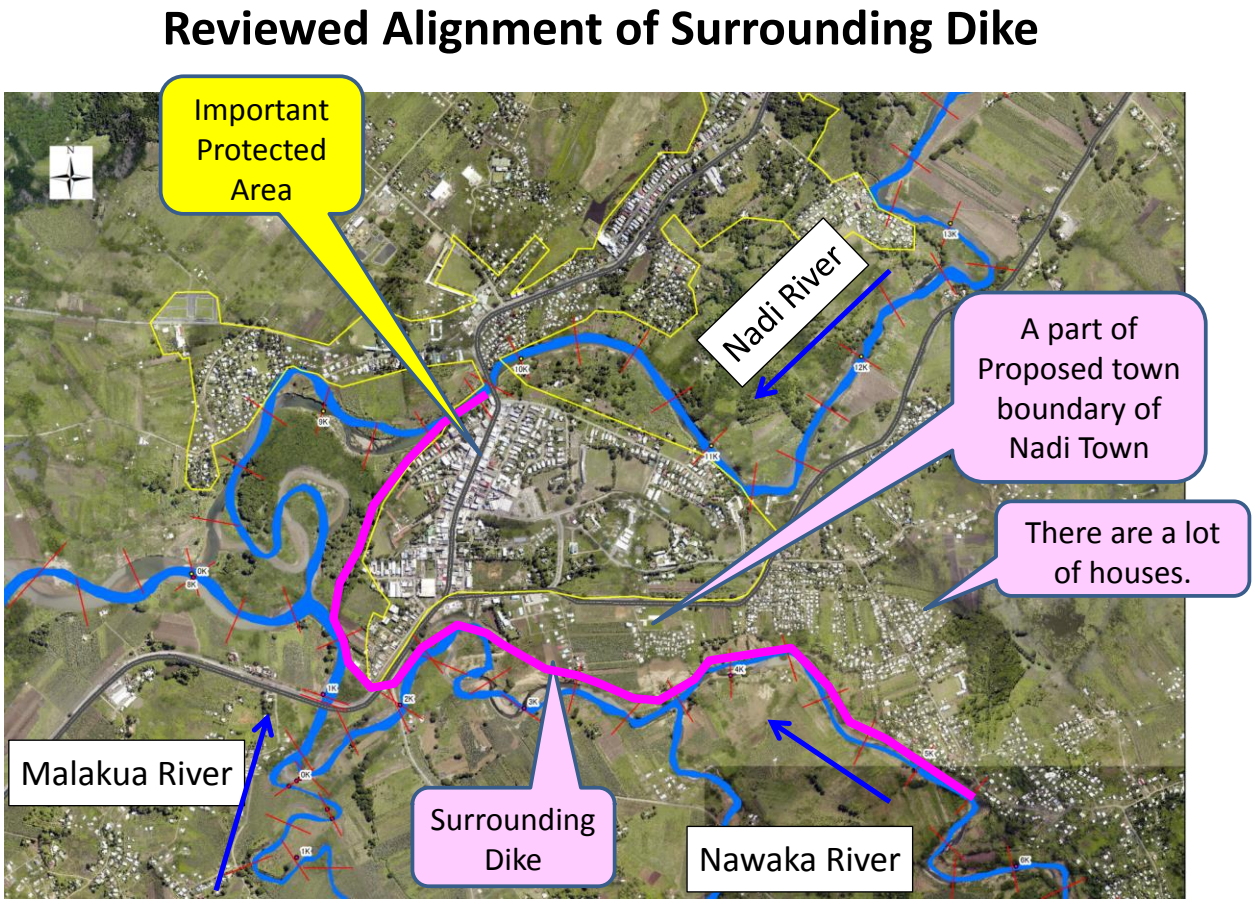


Figure 7-21 Layout of Surrounding Dike around Nadi town

4) Ring Dike in Downstream Area

The ring dike is constructed in the downstream area which is a natural retarding basin to protect the specific community from the negative impact of inundation depth increase by increase of inundation volume which is caused by the river widening in the middle stream.

The concrete examination of the ring dike will be described in[(3) Counter Measures for Negative Impact caused by the Priority Project].

5) Short Cut in Tributaries

The short cut is implemented to reduce the negative impact of increase of inundation depth due to stagnation of flood discharge caused by the surrounding dike around Nadi town.

The concrete examination of the short cut will be described in [(3) Counter Measures for Negative Impact caused by the Priority Project].

(3) Counter Measures for Negative Impact caused by the Priority Project

In case that the priority project the river widening and the surrounding dike around Nadi town are implemented in the priority project, the negative impact of increase of inundation depth occurs in the downstream area of Nadi River main stream and tributaries.

The negative impact in the downstream area of main stream is due to the mainly increase of inundation volume induced by the river widening, of which increase is around a few cm～30cm, and the negative impact in the tributaries is due to the stagnation of flood discharge caused by surrounding dike around Nadi town, of which increase is 5～43cm.

The situation of negative impact and the countermeasures for the impact is examined below.

1) Situation of Negative Impact

a) Downstream Area in Nadi Main Stream

The result of inundation analysis without flood control structure is as shown in Figure 7-23 and that of with the river widening only is as shown in the Figure 7-24, and difference of inundation depth in the both cases is as shown in Figure 7-25. The yellow colored area in Figure 7-25shows occurrence area of negative impact.

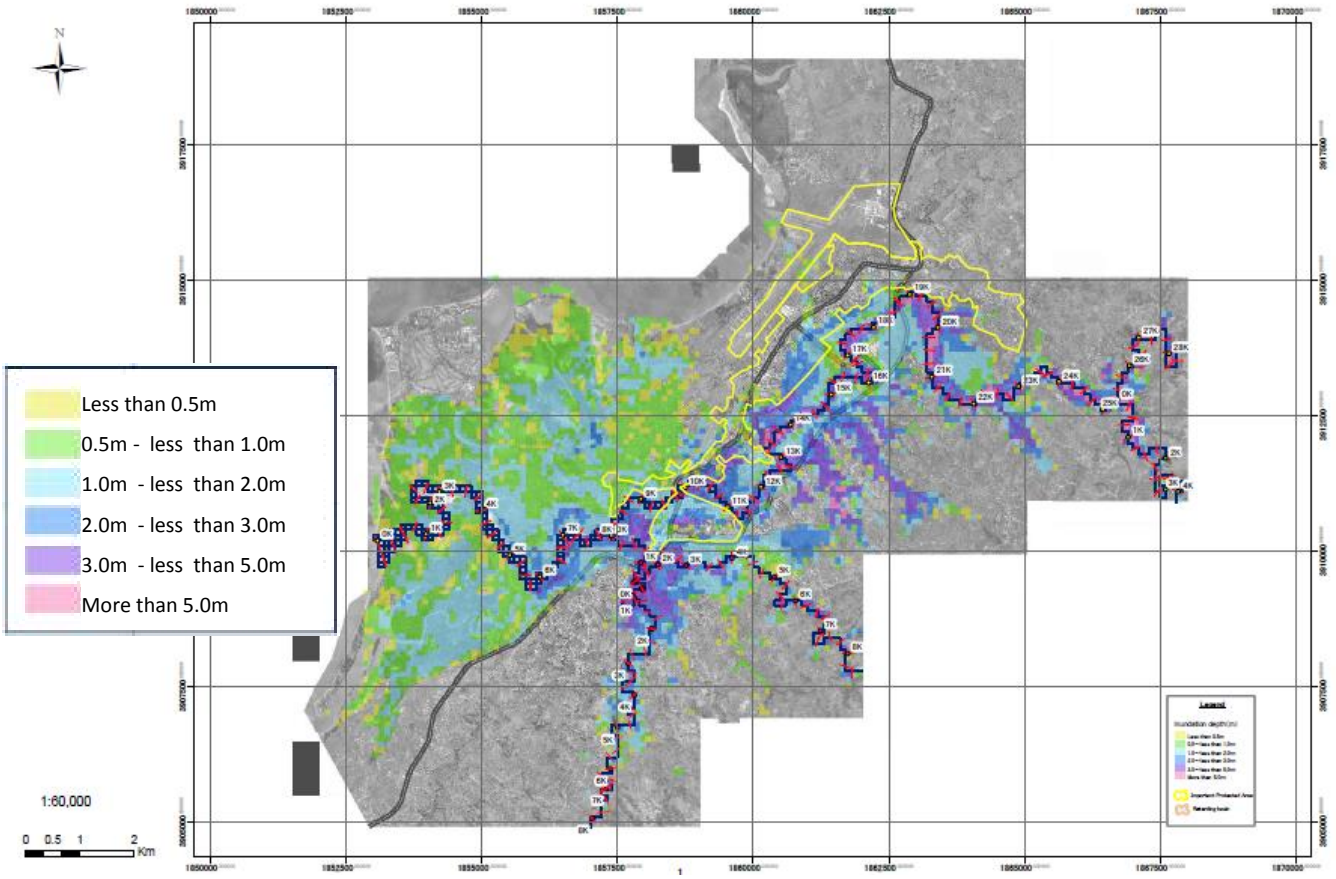


Figure 7-22 Inundation Analysis Result without Flood Control Structure

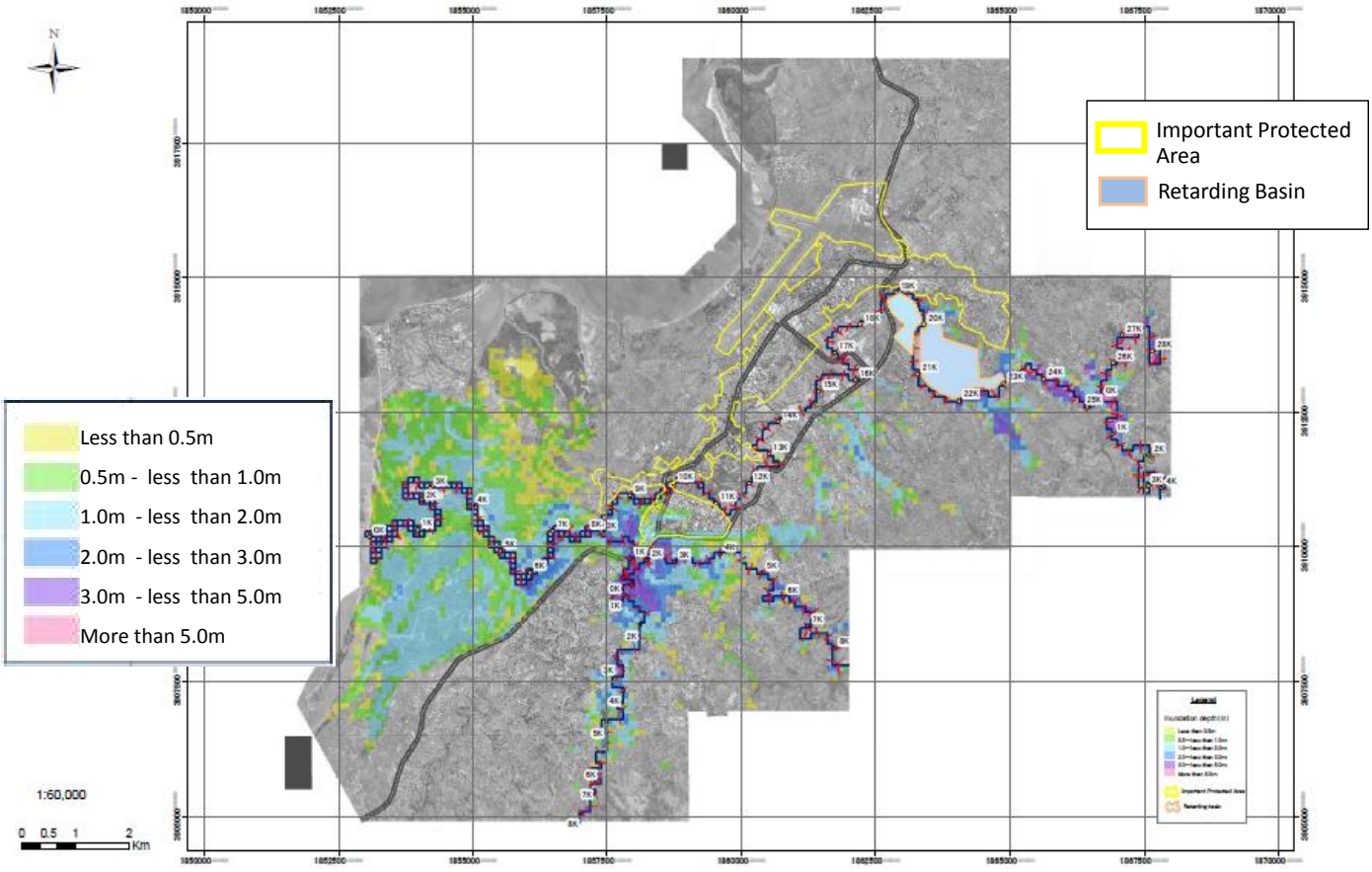


Figure 7-23 Inundation Analysis Result with River Widening only

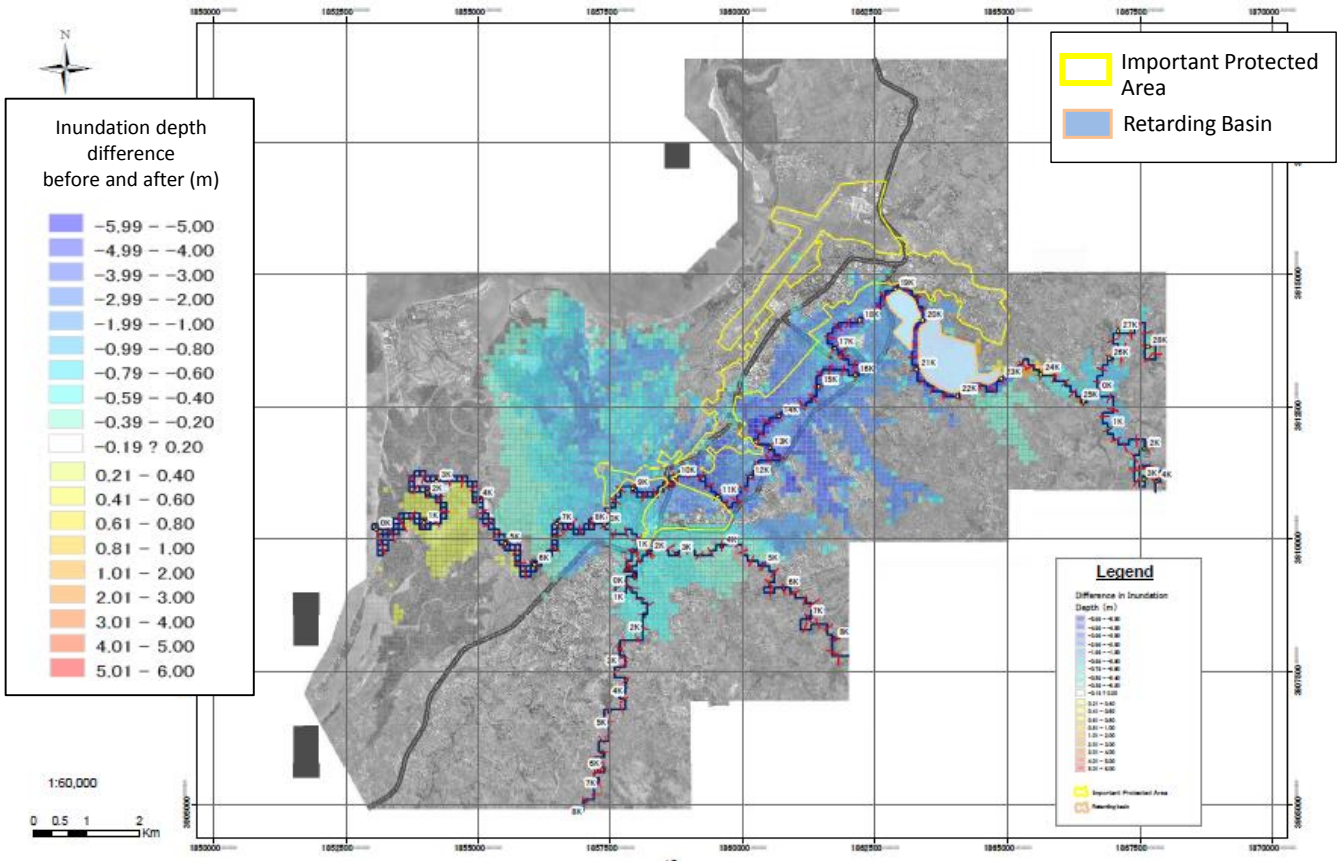
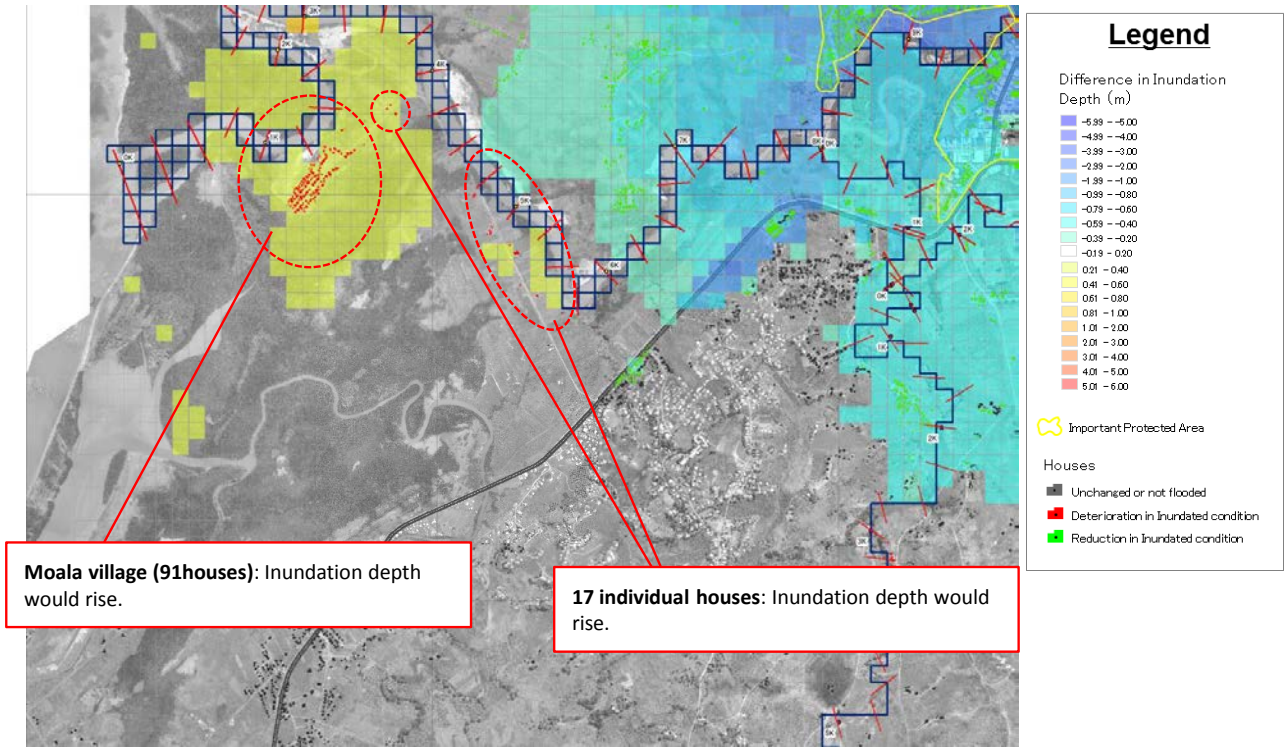
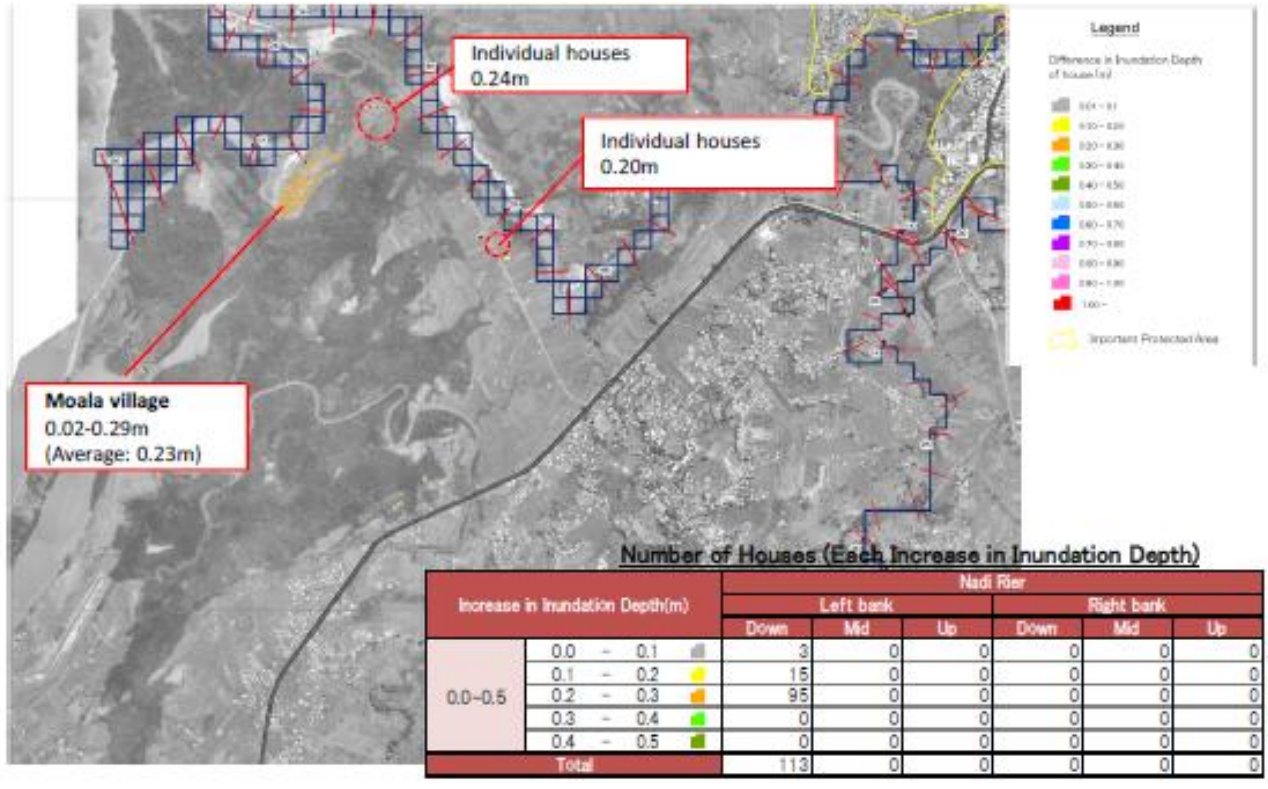


Figure 7-24 Difference Diagram between Figure 7-23 and Figure 7-24

The detail of negative impact occurrence is shown in Figure 7-26. In the housings of the community in the downstream area and scattered housings, the increase of inundation depth of 1cm~30cm is observed.

Difference in Inundation Depth and Distribution of Houses





Number of Houses (Each Increase in Inundation Depth)

Increase in Inundation Depth(m)		Nadi River					
		Left bank			Right bank		
		Down	Mid	Up	Down	Mid	Up
0.0-0.5	0.0 - 0.1	3	0	0	0	0	0
	0.1 - 0.2	15	0	0	0	0	0
	0.2 - 0.3	95	0	0	0	0	0
	0.3 - 0.4	0	0	0	0	0	0
	0.4 - 0.5	0	0	0	0	0	0
Total		113	0	0	0	0	0

Figure 7-25 Occurrence of Negative Impact in Downstream Area of Main Stream

b) Area of Tributaries

The result of inundation analysis after implementation of the river widening including upstream retarding basin A and B, and the surrounding dike around Nadi town is as shown in Figure 7-27. And the difference of inundation depth between Figure 7-27 and Figure 7-23 without Flood Control Structure is as shown in Figure 7-28. The yellow colored area in Figure 7-28 is negative impact of increase of inundation depth occurrence area.

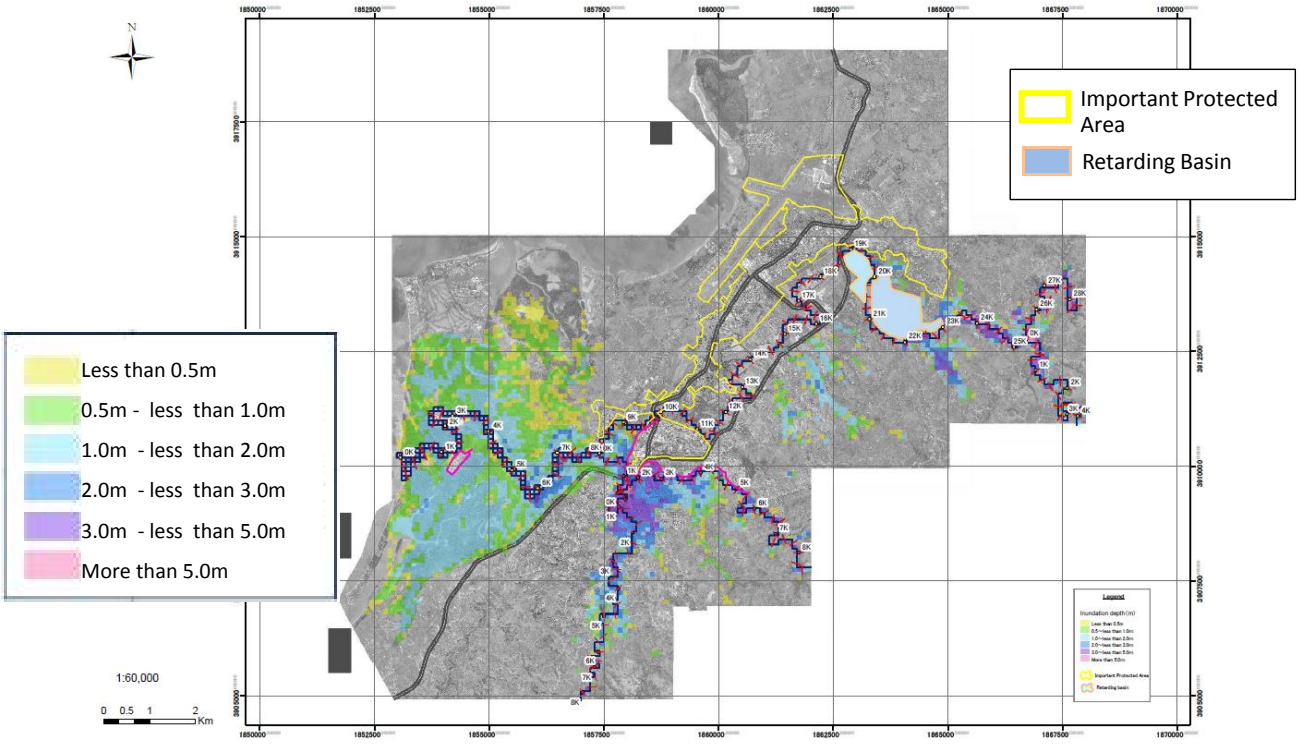


Figure 7-26 Inundation Analysis after River Widening and Surrounding Dike around Nadi town

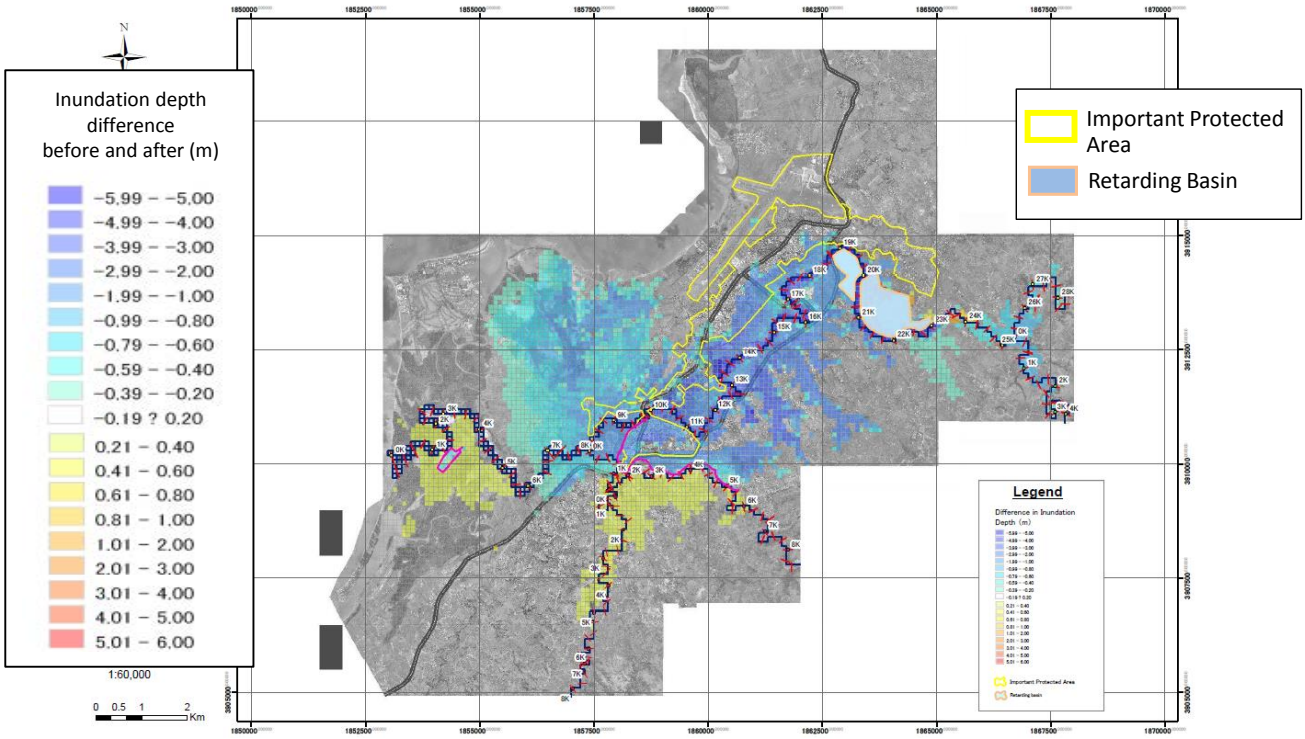
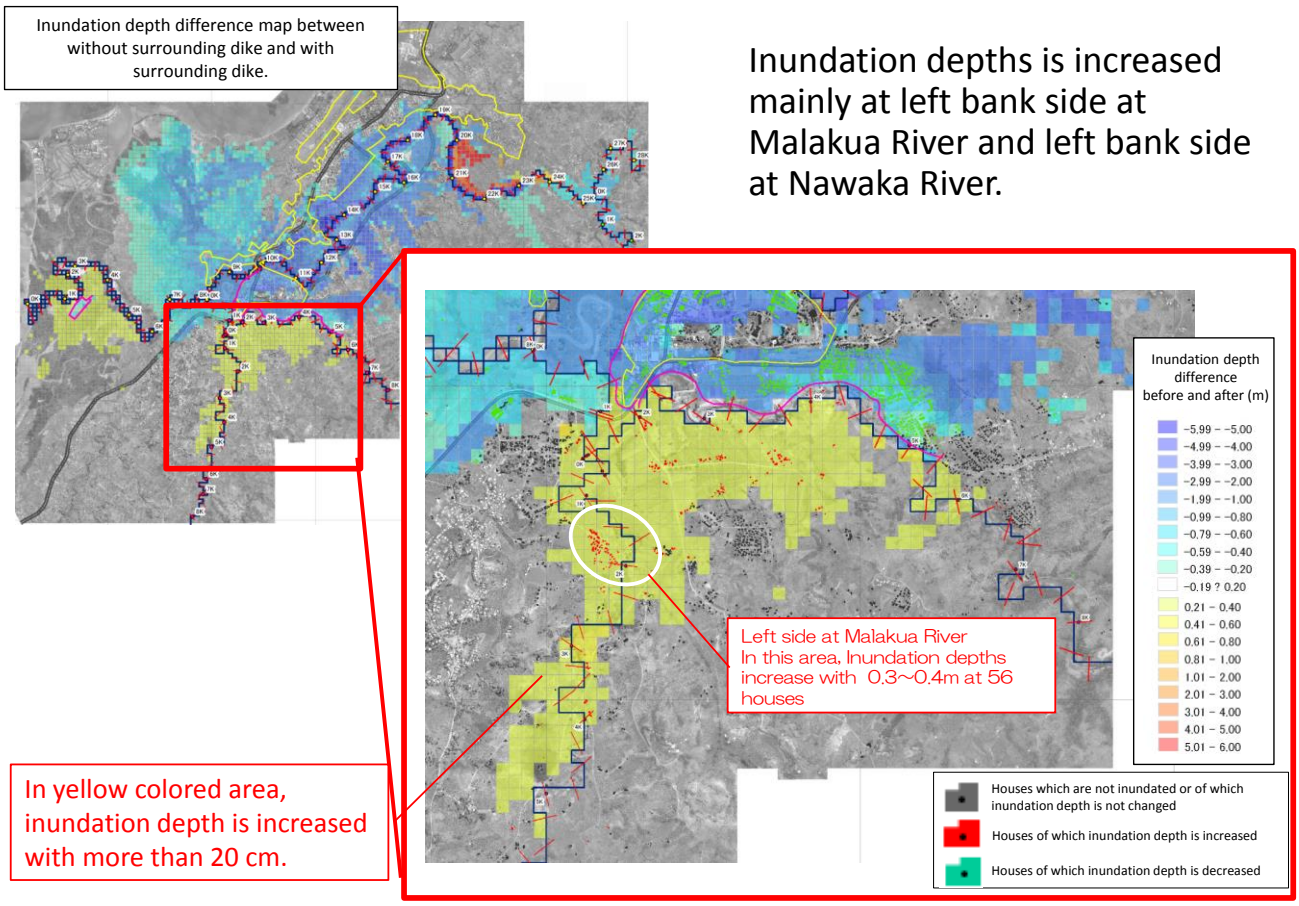


Figure 7-27 Difference Diagram between Figure 7-23 and Figure 7-27

The detail of occurrence condition of the negative impact is as shown in the Figure 7-29. In the 188 housings in the tributaries area the increase of inundation depth from 5cm～43cm is observed.



Number of houses affected and Maximum Increased Inundation Depth

Block	Houses	Increase in Inundation Depth(m)		
		Max	Min	Average
Nadi Left bank Downstream	0	0.00	0.00	–
Nadi Left bank Midstream	0	0.00	0.00	–
Nadi Left bank Upstream	0	0.00	0.00	–
Nadi Right bank Downstream	0	0.00	0.00	–
Nadi Right bank Midstream	0	0.00	0.00	–
Nadi Right bank Upstream	0	0.00	0.00	–
Malakua Left bank	65	0.37	0.16	0.35
Malakua Right bank	12	0.43	0.05	0.20
Nawaka Left bank	104	0.36	0.06	0.31
Nawaka Right bank	7	0.34	0.07	0.17
Namosi Left bank	0	0.00	0.00	–
Namosi Right bank	0	0.00	0.00	–
Total	188	0.43	0.01	0.31

2.5% (total : 7,500 houses)

Increased Depths and Number of houses affected

Increased Inundation Depth (m)		Malakua River		Nawaka River		Total
		Left Bank Side	Right Bank Side	Left Bank Side	Right Bank Side	
Number of houses by increased inundation depth	0.0 – 0.1	0	5	1	1	7
	0.1 – 0.2	2	0	4	4	10
	0.2 – 0.3	7	4	6	1	18
	0.3 – 0.4	56	2	93	1	152
	0.4 – 0.5	0	1	0	0	1
Total		65	12	104	7	188

Figure 7-28 Occurrence of Negative Impact in Tributary Areas

2) Counter Mesures for Nagative Impact

a) Basic Policy of Examination of Negative Impact

The counter measures for the negative impact is examined by setting the criteria based on the inundation situation, housing and asset conditions in field as described in the next section b). And following the criteria the counter measures will be implemented.

b) Criteria of Counter Measures for Negative Impact

① Objective Area for Counter Measures

The counter measures for the negative impact are implemented in the area where the increase of inundation depth is more than 20cm and housings and so on exist. And the counter measures are not implemented in the area where the increase of inundation depth is less than 20cm and no housings and so on exist.

A) Target area of Increasing Inundation depth by negative impact exceed more than 20cm.

- In the area, residential house/ or public building exist.
- Beside, No residential house/ No public building are not target area of measure

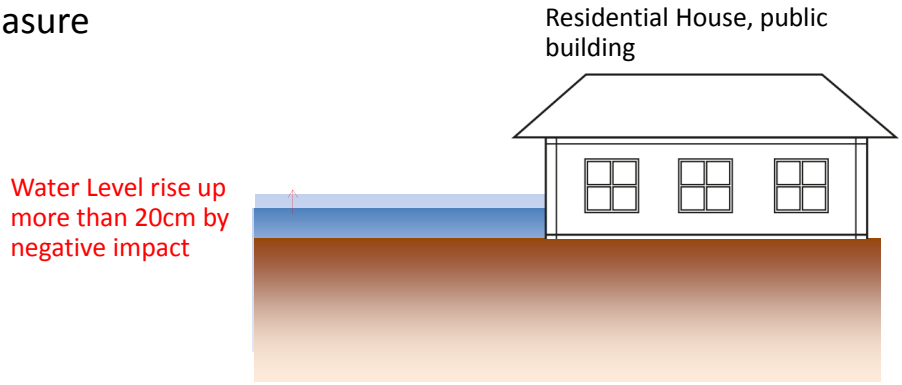


Figure 7-29 Objective Area of Counter Measure for Negative Impact

② Threshold Height of Negative Impact Counter Measures

The negative impact counter measures are implemented in the area described above section ①. The counter measures are implemented to the level which the inundation condition in damaged housing dose not become remarkably worse. Concretely, the inundation depth in the damaged house is classified three (3) categories, such as less than 30cm, more than 30 cm to less than 300 cm and more than 300cm, and the appropriate counter measures are implemented so that the inundation level dose not shift from lower level to upper level. Figure 7-31 explains the outline of application of threshold height.

The threshold height of 30cm and 300cm was confirmed based on the field survey of housing conditions in the field of the objective area which are as shown in Figure 7-32.

B) <u>In order to establish rules to ensure even decision in the mitigation measure plan</u>, the following inundation rank with difference water depth are employed.

i. According to the survey of residential house in the target area, **<u>threshold</u>** height of house is set as 30 cm. (see figure)

ii. Second floor level set as more than 300 cm.(see figure)

Target indicator for Negative impact to measure is set up to **<u>ZERO number of houses</u>** by the following **<u>increasing depth of flooding</u>**.

1) **Increasing Inundation depth <u>exceed 30 cm</u>**
…… height of one floor house building

2) **Increasing Inundation depth <u>exceed 300 cm</u>**
…… height of Second floor of house building

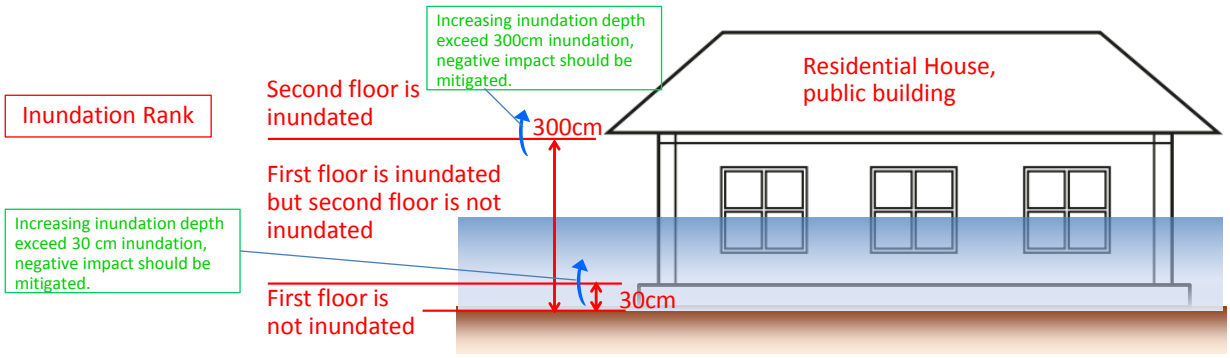


Figure 7-30 Explanation of Threshold Height for Negative Impact Counter Measure

Site Survey for Residential Houses in the Target Area

Figure 7-31 Field Survey of Housing in Objective Area

c) Examination of Negative Impact Counter Measures

① Downstream Area of Nadi River Main Stream

In the downstream area of Nadi River main stream there are two groups of housings incurred by the negative impact, they are 99 housing gathered together formulating a community and housings scattered.

As to the 99 housing group, the ring dike which is a part of the Master Plan is to be implemented in the priority project prior to implementation of Master Plan as a counter measures for negative impact

As to the scattered housings, the counter measures such as rebuilding to stilt house, relocation, compensation and so on are likely considered. Although the counter measures will be disused and examined with related agencies in the Feasibility Study, the final measures will be determined through discussions with residents in the implementation stage of the Project.

The difference of inundation depth after implementation of ring dike is as shown in Figure 7-33. The figure shows the inundation is prevented by the ring dike so that the negative impact is reduced. The scale of the ring dike will be described in[8.4 Ring dike].

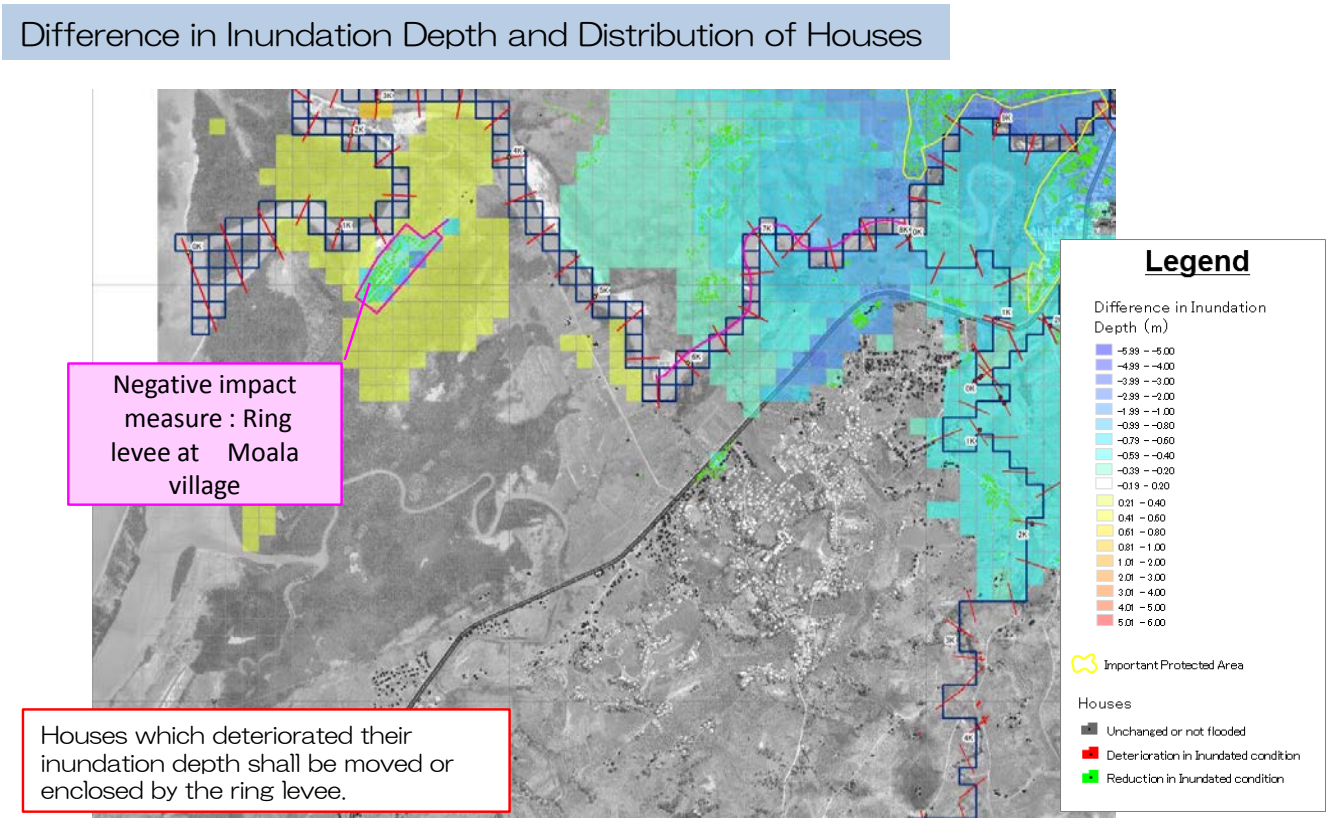


Figure 7-32 Difference of Inundation Depth after Implementation of Negative Impact Counter Measure in Down Stream of Nadi River Main Stream

② Tributary Areas

The inundation depth increase 5cm~43cm in 188 housings in the tributary areas. There are two alternative of the counter measures, one is the implementation of retarding basin group which is a part of the Master Plan for tributaries and the other is to construct short cut by improvement of alignment of tributaries. The layout of the both alternative is as shown in Figure 7-34.

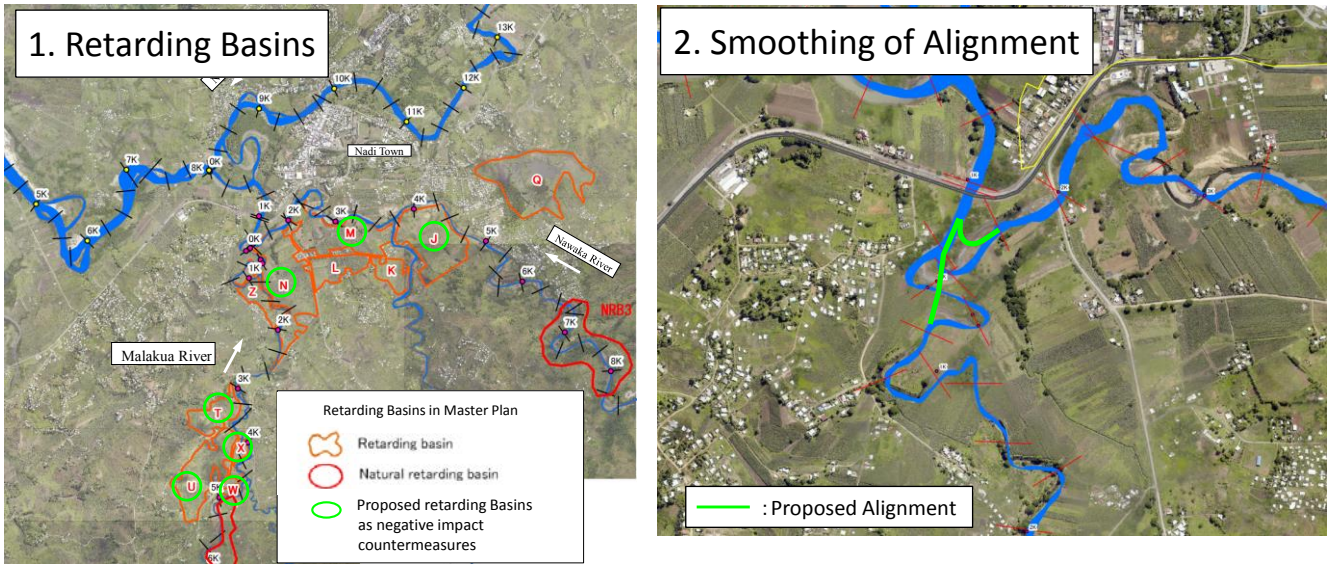
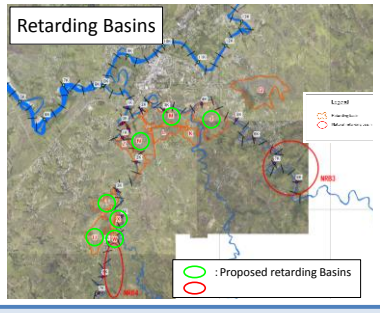
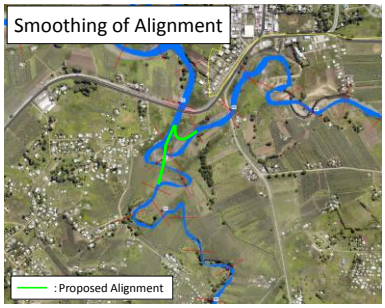


Figure 7-33 Alternatives of Counter Measure for Negative Impact in Tributaries

The results of comparison of the both alternatives are as shown in Table 7-13. According to the table the short cut is superior than the group of retarding basins, the former is adopted as the negative impact counter measure.

Table 7-13 Comparison of Alternatives of Negative Impact Counter Measures in Tributaries

Countermeasures against negative impact			
Effectiveness of countermeasures	Evaluation of Effectiveness	● Mitigate negative impact ● After mitigation, although 113 houses are affected negatively, but the situation is not applicable to negative impact criteria. ● This method does not affect downstream because flood water is retarded in tributaries' basin.	● Mitigate Negative impact ● After mitigation, although 132 houses are affected negatively, but the situation is not applicable to negative impact criteria. ● After implementation of shortcut, flood water flow smoothly and affect downstream, the impact to down stream is very small. Inundation depth in downstream is increased with only 2cm.
Construction	Construction Quantity	Approx. 185ha	Approx. L=500m, W=30m, 1.5ha
	Rough Construction Cost (Ratio)	FJD 91,000,000 (1.0)	FJD 3,000,000 (0.03)
Feasibility		Difficult in short term to get consensus and land acquisition	Supposed to be Easier than retarding basins to construct
Consensus		Difficult in short term to get consensus	Supposed to be Easier than retarding basins to get consensus
Judgement		—	Better

The difference of inundation depth after implementation of short cut in the tributaries is as shown in Figure 7-35. By the short cut the stagnation of flood discharge is improved and the area incurred by negative impact is remarkably reduced comparing with Figure 7-29. The scale of short cut will be described in [8.2 River Channel Plan in Main Stream and Tributaries]

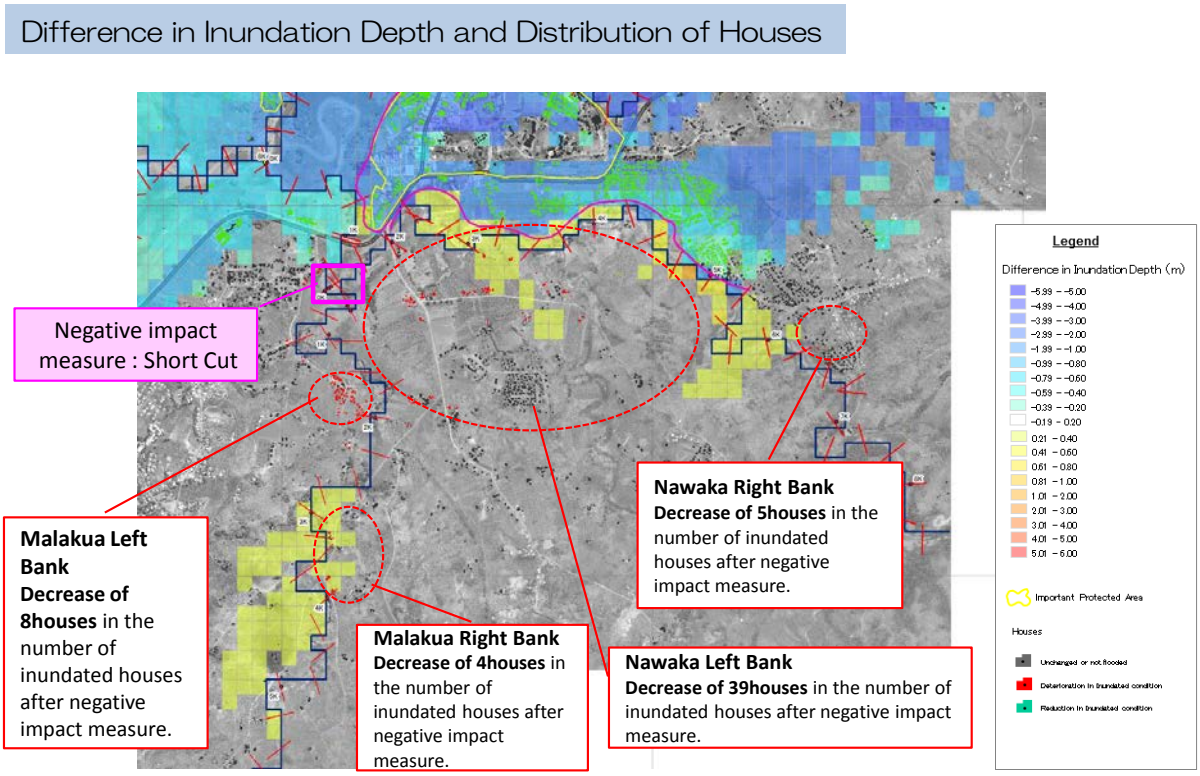


Figure 7-34　Difference of Inundation Depth after Negative Impact Counter Measures in Tributaries）

The inundation depth after the negative impact counter measures is as shown in Figure 7-36.

Although the inundation depth of 10cm～3.1m occurs, the negative impact is restricted to less than 30cm, and there are no housing of which inundation level shifting lower level to upper level so that the negative impact counter measures are likely to be sufficient.

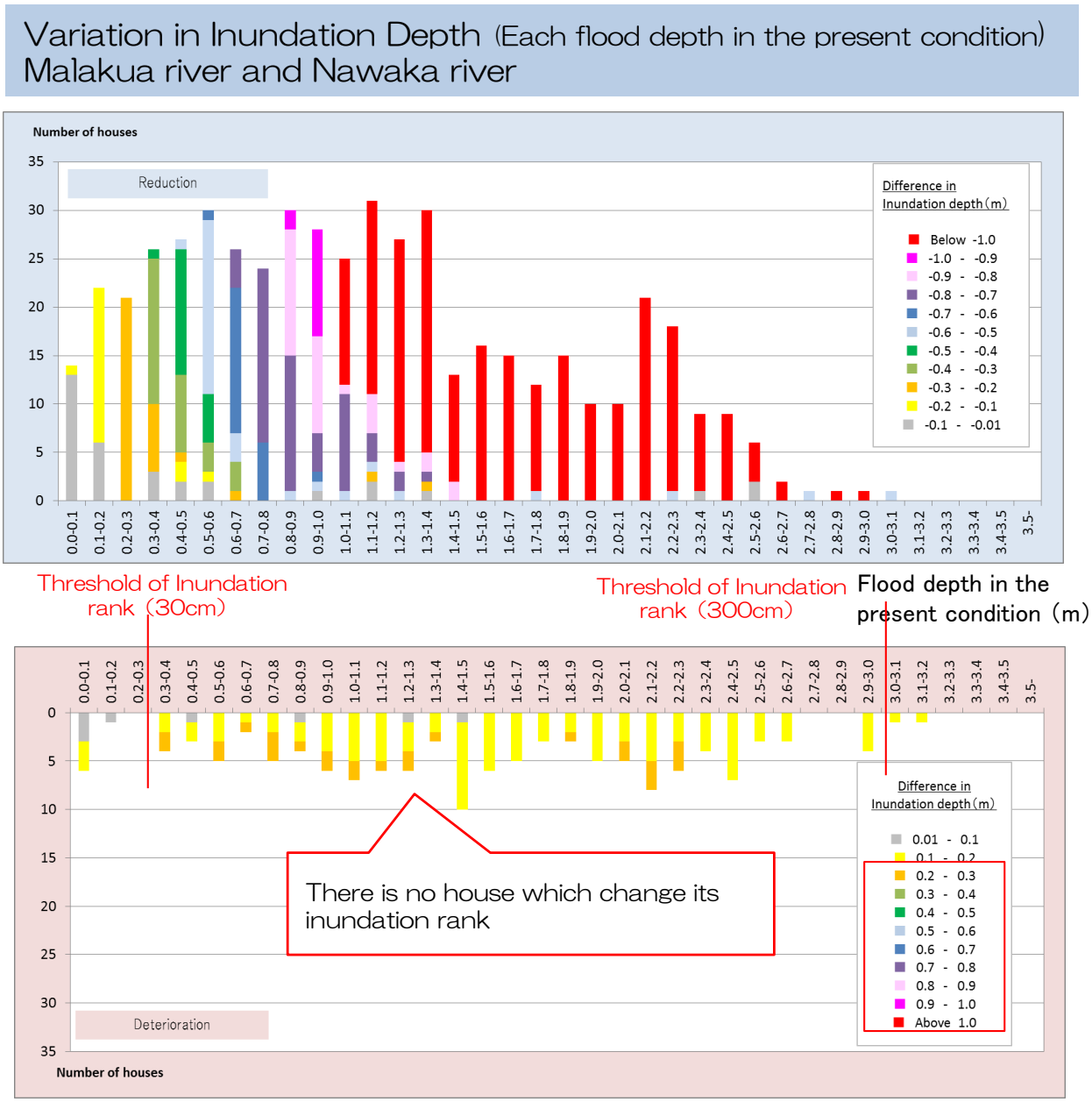


Figure 7-35 Inundation Depth after Negative Impact Counter Measures in Tributaries

(4) Final Flood Control Structures in Priority Project

In conclusion, the final flood control structures in the Priority Project are as shown in Figure 7-37 and Table 7-14.

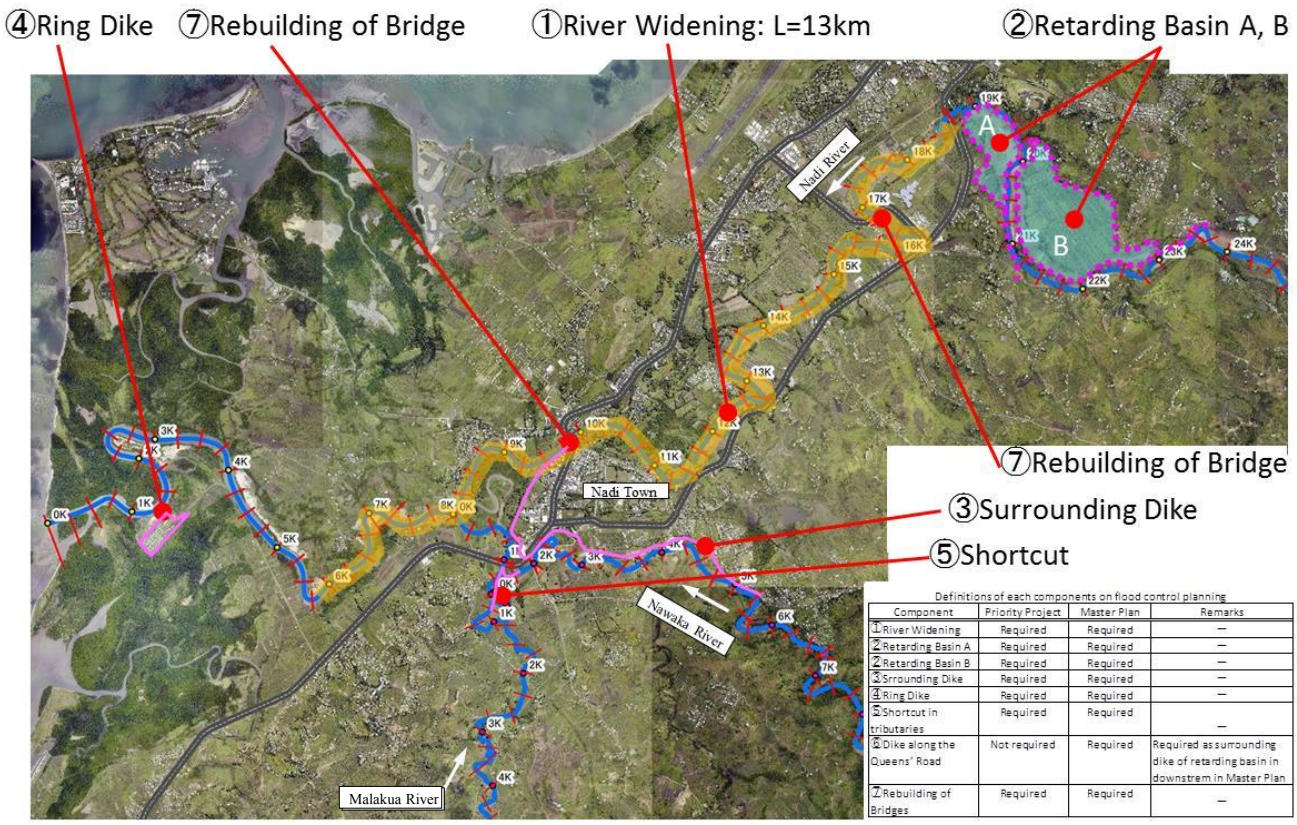


Figure 7-36 Final Components of Priority Project

Table 7-14 Final Components of Priority Project

Definitions of each components on flood control planning

Component	Priority Project	Master Plan	Remarks
①River Widening	Required	Required	—
②Retarding Basin A	Required	Required	—
②Retarding Basin B	Required	Required	—
③Srrounding Dike	Required	Required	—
④Ring Dike	Required	Required	—
⑤Shortcut in tributaries	Required	Required	—
⑥Dike along the Queens' Road	Not required	Required	Required as surrounding dike of retarding basin in downstrem in Master Plan
⑦Rebuilding of Bridges	Required	Required	—